Essays on retirement income provision

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Chapter 1

Introduction

In recent decades, there have been rapid changes in the world's demographic structure. Population aging is a serious problem faced by many countries in the world. The world old-age dependency ratio, measured as the ratio of people aged 65 or above to those aged 15-64, has increased from 10.9% to 12.6% since the beginning of the 21th century. As for the more developed regions, the old-age dependency ratio has reached the level of 26.7% in 2015.[1] The increase in the old-age dependency ratio is a result of lower fertility rate in combination with longer life expectancy. According to the World Bank, the fertility rate has decreased from 4.96 in 1960 to 2.45 in 2014, and at the same time, the life expectancy at birth has increased from 52.48 to 71.46 years.[2] In Europe, the fertility rate has decreased from 2.66 to 1.60 since the early 1950's, while the life expectancy at birth has increased from 63.59 to 77.01 years and life expectancy at age 60 has increased from 16.78 to 21.93 years.[3]

As people approach an advanced age, their work capacity gradually decreases and their health condition generally is getting worse. How to support those elderly people becomes more and more important in the world, given that both the proportion of elderly people and their remaining life expectancy are increasing. In most developed countries, the current existing pension systems are under pressure, and reforms are carried out in order to face the aging society. In the developing world, related social welfare systems are introduced. Many countries set up a state pension system (funded or pay-as-you-go, or a mixture of the two) for their citizens as a main source of their post-retirement income. For instance, a new rural social pension system aimed at the whole rural population was launched in China in 2009. Not only the governments

[1] The data are obtained from the World Population Prospects, the 2015 Revision. The more developed regions comprise Europe, Northern America, Australia, New Zealand and Japan.

[2] The World Bank: `http://data.worldbank.org/indicator/SP.DYN.LE00.IN`.

[3] Population Division of the United Nations: `https://esa.un.org/unpd/wpp/Download/Standard/Mortality/`.

are aware of the aging problem, but also the private sectors are aware of it and take it as an opportunity to develop the old age care industry and to introduce financial innovations. Private pension funds and annuity products are popular in many countries. In recent decades, equity release products are being introduced to free up the housing equity for the asset-rich-cash-poor elderly. In this thesis, we focus on three topics out of the broad range of old-age supporting.

In Chapter 2, we analyze the sustainability of a new regulatory framework for the Dutch pension funds. The new regulatory framework came into force in 2015, replacing the earlier system that had existed since 2007. The Dutch pension system consists of three pillars, namely the state pension, the collective pension schemes, and the individual pension products. As a result of the financial crisis, the prolonged low interest rate period and the aging population, the second pillar of the pension system has been under pressure, reflected by underfunding of the pension funds. The underfunding triggered recovery measures, and questions were raised concerning the fairness and effectiveness of that system. Thus, a revision, known as the new Financial Assessment Framework (abbreviated "nFTK" in Dutch), was introduced. In this chapter, we carry out an analysis of the new framework based on a simulation study, focusing on economic scenarios and leaving aside the possible consequences of unanticipated changes in mortality. We use a stylized pension fund that has the same demographic structure as the Dutch population. The fund follows a fixed-mix investment policy and keeps contributions constant, except when reductions are permitted under the nFTK rules. Economic scenarios are generated by a VAR model. We find that although average funding ratios are high, fully wage-indexed pensions are still achieved in only approximately 60% of the scenarios. Under the best scenarios, the policy funding ratio can soar to 700% while under the worst scenarios, replacement ratios can drop to under 40%. Under those circumstances, the nFTK will probably be changed. Therefore, it fails to make the contract complete. There is a "reverse Ponzi " effect in the system. The nFTK is slower in giving indexation than cutting benefits, therefore it tends to shift wealth to the future indefinitely. The pension fund will in most scenarios become rich; however, the participants cannot benefit from the high policy funding ratio. Given that, the nFTK encourages a conservative investment policy. The participants cannot take advantage of the high return from a riskier investment, but they have to bear the losses. Previous studies of the regulatory system for Dutch collective pension funds include Bikker and Vlaar (2007), van Rooij et al. (2008), Nijman et al. (2013), and van Stalborch (2012). Those studies focus on the consequences and intergenerational fairness of the earlier system. To our knowledge, this is the first paper that carries out an extensive analysis of the nFTK.

Chapter 3 studies reverse mortgage products. For elderly people, housing equity takes up a large proportion of their accumulated wealth. A reverse mortgage is one of the products available on the market that allow elderly homeowners to convert (part of) the value of their house value into cash without repayment, while staying in their home (until death or permanently moving out of the home due to other reasons). Most of the existing reverse mortgage products include a guarantee that the loan value cannot exceed the house value when the contract ends, which is called the No-Negative-Equity-Guarantee (*NNEG*). Previous studies on reverse mortgage typically consider from three different aspects. The first aspect is focusing on the market volume of the product. The demand for reverse mortgages was very small when the product was first introduced (Venti, Wise, 1991), and it began to expand since the New Millennium (Chou et al., 2006, Shan, 2011). The second aspect concerns the reason of the low demand. Bequest motives, adverse selection and moral hazard, as well as the complexity of the product all play a role in reducing the market volume (Davidoff, 2010, Michelangeli, 2008, Chou et al., 2006, Davidoff et al., 2015). The third aspect of the literature is focusing on the pricing and risk analysis of the product. Longevity risks, house price risks and the price of the *NNEG* are all heavily discussed (Wang et al., 2008, Li et al., 2010, Yang et al., 2011, Chen et al., 2010, Lee, 2012, Shao et al., 2015, Ji et al., 2012.). Although different models, which are potentially misspecified, have been developed to price the *NNEG*, model risk is typically not investigated. We evaluate the cash flows of different reverse mortgage designs and the implied value of the embedded *NNEG*, taking into account model risk. We compare the values of the *NNEG* and their sensitivities to different parameters generated from two popular models in the literature for the house price process, i.e., the Geometric Brownian Motion model and the VAR model. We calibrate the models using prices of regular mortgages and determine the corresponding price ranges for reverse mortgages. We find quite substantial price ranges for both models, indicating that there is substantial model risk in pricing the *NNEG* in reverse mortgage products. Moreover, the degree of model risk is larger in the VAR model than in the GBM model. Among the different parameters that affect the price of the *NNEG*, we find that it is most sensitive to the probability distribution of the future house price, which is reflected by the dividend rate in the GBM model and by the house price increase rate in the VAR model. With considerable model risk, reverse mortgage providers might be reluctant to provide the product or they may charge a higher premium to compensate their risk. This might keep some potential buyers out of the market.

In chapter 4, we investigate the impact of a newly introduced rural pension system in China. In 2009, the Chinese Government introduced the New Rural Social Pension Insurance program (NRSPI). The program was extended to nationwide scale in 2012. This chapter investigates the effect of the NRSPI on the retirement and old-age labor supply pattern in China using two-wave nationwide survey data. After using instrumental variables to control for the endogenous bias, we find that receiving pension benefits from the NRSPI can substantially increase the likelihood of retirement and decrease the number of working hours for females, even though the amount of pension benefits of the NRSPI is far below the minimum cost of living. We further decompose the labor supply into agricultural labor supply and non-agricultural labor supply, and find that most of the decrease in labor supply is from agricultural labor supply. The NRSPI program is a quite unique social security program, given its modest pension benefit and the pure income effect brought by the program. Previous studies that show the pension systems shift people's retirement behavior by providing economic incentives focused on pension systems providing the main income for the elderly involved (Gruber and Wise, 2008). Contrarily, the basic pension benefit of the NRSPI program is far below the minimum cost of living. Thus, this pension program gives us a chance to study whether and, if so, to what extent people respond to such a small amount of money. Besides, the pension benefits from the NRSPI program are not contingent on the work status. Pensioners can continue to work while receiving pension benefits; thus, joining the pension program generates a pure income effect. Although there are many papers that discuss the relation between social security programs and the retirement decision, this study helps us understand the retirement behavior under a unique social security program. This study also contributes to the literature regarding the impact of non-financial factors by investigating the role played by the regional characteristics in the retirement decision. We find that rural dwellers behave substantially differently in terms of retirement pattern from people living in the cities, even after controlling for financial situation, demographic background, family structure and so on.

In terms of methodology, both simulation and estimation methods are used in this thesis. There is some overlap in the methodology between chapter 2 and chapter 3. In both chapters, we set up a Vector-Auto-Regression (VAR) model to derive the term structure of interest rates, to capture the co-movement of different macro-economic variables, and to simulate future economic scenarios. In chapter 3, we also use a GBM model to compute the price of the reverse mortgage product as a comparison to the VAR model. The house price in the GBM model is assumed to follow a Geometric Brownian Motion and the *NNEG* is priced as a Black-Scholes put option on the net house price. Chapter 4 is an empirical study; an Instrumental Variable Panel Data model is used to analyze the effect of the NRSPI program on labor supply decision. The instrumental variable approach is adopted to solve the endogeneity problem, and a panel data model is used for better control of the individual effect.

Chapter 2

An Evaluation of the nFTK

2.1 Introduction

In 2007, the Dutch government replaced the obsolete Pension and Savings Funds Act (Pensioen- en Spaarfondsenwet), which dated from 1952, with a new Pension Act. The new law was innovative in its use of funding ratios based on market value as an indicator of the financial health of collective pension funds. In the Netherlands, these funds play a very important role in providing retirement income, with a total asset value in 2014 of more than 160% of Dutch GDP. As a result of the financial crisis of 2008 and the ensuing prolonged period of low interest rates, however, the recovery measures triggered by underfunding under the terms of the new law quickly became a reality. Millions of retirees were affected by reductions in their nominal benefits, and many questions were raised concerning the fairness and effectiveness of the existing regulatory framework. While the debate continues with regard to restructuring retirement income provision systems, a revision of the Pension Act was introduced in 2015. The new law is commonly known as the "new Financial Assessment Framework" (nieuw Financieel Toetsingskader, or nFTK). Modifications with respect to the 2007 FTK include the following: replacing the funding ratio with an averaged version, called the "policy funding ratio"; placing less emphasis on the contributions level as an instrument for recovery; and tightening the conditions under which indexation of benefits may be applied. These modifications are intended to lead to a system that is more sustainable and maintains a better balance between generations.

We carry out an investigation of the performance of the nFTK over a fifty-year horizon, given a stylized pension fund combined with specific choices in terms of the contribution and investment policies and using a set of model-based scenarios. In particular, we focus on the evolution of the funding ratio and the indexation ratio over this time horizon. The funding ratio is defined as the ratio of the fund's assets to its liabilities. We define the indexation ratio as the ratio of the actual pension entitlements to the pension entitlements under full indexation. Thus, the indexation ratio is equivalent to the replacement rate for pensioners. And full indexation means full wage indexation. Since using the replacement rate for workers is not appropriate, we use the indexation ratio instead of the replacement rate to quantify the extent to which the pension system can provide fully indexed pension entitlements for both workers and retirees.

The stylized pension fund in our study has the same demographic characteristics as the Dutch population as a whole. We assume that the fund keeps contributions at a constant level, unless reductions are allowed under the nFTK. Raising contributions would be required under the nFTK in situations in which newly accrued rights are expensive, in other words, during prolonged periods of low interest rates. Since we calibrate interest data from 1990 on, however, such scenarios hardly occur in our scenario set. Investment policy under the nFTK is not specified beyond the 'prudent person' rule. For the purposes of the simulation study, we assume that our stylized pension fund follows a simple fixed-mix policy, with 35% in stocks and 65% in ten-year bonds; no separate interest rate hedge is assumed beyond the protection already offered by the bond portfolio. In our scenario set, we concentrate on economic risks, leaving longevity risks aside. Scenarios are generated by a vector autoregressive (VAR) model that accounts for the variability in price inflation, wage inflation, stock returns, and long-term and short-term interest rates. The use of scenario sets to perform an analysis like we do is well established; early references on this methodology include papers by Wilkie (1984, 1995), Mulvey and Thorlacius (1998), and Boender (1997, 1998).

The model we use to generate the scenario set is calibrated on equity data, interest rate, and inflation data starting from 1990. Therefore, starting from the current low interest rate, interest rates rise on average to levels that are typical of the last 25 years, and there is a substantial equity premium. As a result, we find many scenarios in which funding ratios are high. Nevertheless, the goal of full wage indexation is reached in only about 60% of the scenarios, even on a fifty-year horizon. On the downside, we find that, in bad scenarios (5% quantile), pension benefits fall far behind the level corresponding to full indexation; indexation ratios on a fifty-year horizon reach levels as low as 40%. Based on these outcomes, we conclude that, at least given our stylized pension fund and chosen contribution and investment strategy, improvements might still be needed in the new regulatory framework to deal with the extreme outcomes in a substantial fraction of the scenarios.[1]

Earlier asset-liability studies for pension funds have been conducted by, for instance, Bosch-Príncep et al. (2002) and by Dempster et al. (2003). Shortly after the introduction of the Dutch FTK in 2007, a simulation study of the consequences of the new system was undertaken by Bikker and Vlaar (2007). Subsequent studies of the regulatory system for Dutch collective pension funds and proposed modifications to it include those by van Rooij et al. (2008), Nijman et al. (2013), and van Stalborch (2012). These studies partly emphasize aspects not covered here, such as intergenerational fairness on a market value basis. The policy dilemmas for pension funds under a regulatory regime based on market valuation of nominal liabilities have been discussed by Kortleve and Ponds (2009). These dilemmas continue to exist under the nFTK; pension funds may look for investment policies that modify the consequences of the system, while balancing the interests of different generations. In the present study, however, we do not attempt to formulate such policies; instead, we assume a fixed-mix investment plan. This allows us to evaluate the performance of the nFTK with respect to a simple but reasonable investment policy.

The organization of the remainder of the paper is as follows. In Section 2.2, we describe our stylized pension fund. In particular, we state our assumptions concerning the choices that the stylized fund makes in various options left open by the nFTK. Section 2.3 describes the economic model from which our scenario set is generated. The main results follow in Section 2.4. We report statistics concerning the distribution of the indexation ratio and the funding ratio, and we also discuss the nature of the relationship of these quantities to economic determinants such as asset returns and wage inflation. In Section 2.5, we give some design recommendations. Finally, our conclusions are presented in Section 2.6. Additional information, including technical details, can be found in the appendix.

2.2 An Implementation of the nFTK

2.2.1 Stylized Pension Fund Set-up

In this section, we set up a stylized pension fund to facilitate the analysis of the nFTK. The appendix, to which we shall occasionally refer, contains the technical details. We assume our stylized pension fund covers all of the Dutch population over the age

[1] Alternatively, the pension fund might change its contribution and/or investment policies in extreme outcomes. We do not investigate this alternative in this paper.

of 25. The demographic structure of our pension fund is taken directly from the real Dutch demographic structure for 2009, as obtained from the Human Mortality Database.[2] The maximum attainable age is 110, and the minimum age in this dataset is 0. We assume a constant influx of newborns every year, equal to the generation of newborns in 2009, which allows us to define an open fund with a workforce influx each year. The reason for choosing an open fund rather than a closed fund is that an open fund is more stable in terms of demographic structure. Each year, a new generation of 25-year-olds enters into our pension system. At the same time, there are outflows caused by the deaths of participants. The number of survivals is assumed to evolve according to the most recent forecast mortality table provided by the Dutch Koninklijk Actuarieel Genootschap (Royal Actuarial Society). This mortality table predicts the mortality rates for each age group through the year 2184. The maximum attainable age in the mortality table is 120, but in the population size data, it is 110 years old. We take the lower limit as the maximum attainable age in our study. We work with gender-neutral mortality rates, computed as the average of the male and female mortality rates.

One of the cash inflows for the pension fund is the contributions made by workers. Total contributions are determined by three factors, namely the pension base, the number of workers in the pension fund, and the individual pension contributions. The pension base of each working generation is the wage minus the franchise (a deduction made in view of the existence of the state pension). The individual pension contribution is defined as a fraction of the pension base. We assume that this fraction will be kept constant at a level that is fixed at the beginning of the simulation, except when a reduction is allowed by the nFTK. The amount for the total annual contributions made by each worker is defined as the individual pension contribution times the worker's pension base; the total contribution is the sum of the individual contributions of all workers.

The cash outflow of the pension fund consists of the pension benefits paid to retirees. We consider only payments to retirees and leave additional payments (e.g., to the spouses of deceased participants) out of consideration. To determine the pension payment, we need the pension entitlements of each retired generation, in addition to the number of retirees. The pension entitlements for each generation are built up during their working life. When a new generation comes into the pension fund, the members of that generation will build up a pension entitlement that is a certain fraction of the pension base in that year. Following the latest revision of pension

[2] `http://www.mortality.org`.

rules, this fraction has been set at 1.875%. Before retirement, the pension entitlement will first be indexed and then increased by the pension entitlements accrued in that year. After retirement, there is no further accrual, but indexation may still take place. Given the actual pension entitlements, the total pension payments paid at the beginning of the period is the sum of the pension entitlements for all retirees.

Given the cash outflow and inflow of the pension fund, we can determine the assets at hand. At the beginning of each period, pension payments are made, and at the end of each period, pension contributions are received. We assume that the stylized pension fund invests its assets in a portfolio consisting of 65% bonds and 35% stocks. Therefore, the pension assets at the beginning of each period will be the assets of the previous period, after deduction of pension payments, plus the proceeds of investments and pension contributions. We do not assume any recovery contributions from a sponsor.

The stylized pension fund applies indexation according to a policy ladder, as is usual for Dutch collective pension funds, within the restrictions set by the nFTK. Whether or not full or partial indexation occurs depends on the financial status of the fund. Although one might argue that the option value of conditional indexation should be taken into account when determining the market value of liabilities, in practice the value of liabilities is computed from unconditional liabilities only (i.e., conditional indexation is not taken into account). Based on the current pension entitlements for each generation, we can project current and future pension payments. The value of the liabilities is the discounted value of those pension payments. Discounting takes place on the basis of the current term structure of interest rates for non-defaultable bonds, extended by an Ultimate Forward Rate (UFR). The scenarios generated by our economic model include possible future term structures and allow computation of future UFRs in a manner recommended by the UFR Committee (2013) (see Sections 3.3 and 3.4 in the appendix for details).

The funding ratio is defined as the ratio of the current value of assets to the current value of liabilities. In the proposed revision of the law, a new concept is being introduced, called the Policy Funding Ratio (beleidsdekkingsgraad). The Policy Funding Ratio (PFR) is defined as the 12-month moving average of the actual funding ratio. Because our simulation is on an annual basis, we define the PFR as the average of the current actual funding ratio and the funding ratio of the previous year. The initial PFR in our simulation exercise is set at 104.3%, which not only reflects the current situation of low funding ratios, but also satisfies the lower bound given by the Minimum Required Funding Ratio (MRFR) (see Section 2.3).[3]

2.2.2 Determining the Individual Pension Contributions

Individual pension contributions are set at the beginning of the simulation and will not be raised above the initial level under any scenario. With this assumption, we can see whether the pension fund can meet its goal of providing full indexation without raising contributions. To calculate this contribution, we choose a *term-structure-based pension contribution with cushioning*, among the various options left open by the regulatory requirements. Cushioning is based on the average of the term structures in the past ten years.[4] The individual pension contribution is set such that the total pension contributions made by all workers in a year is equal to the Required Funding Ratio (see next section) times the present value (according to the averaged term structure) of the accrued pension entitlements of those workers within that year. This individual pension contribution in our model turns out to be 16.33%.

2.2.3 Recovery, Indexation, and Repair Policies

Under the nFTK, the behavior of pension funds in various possible states of financial health (as measured by the Policy Funding Ratio) is prescribed in considerable detail. There are five different situations that can arise, which are illustrated graphically in Figure 2.1. The determination as to which situation applies is related to a set of critical levels for the PFR (cf. Table 2.1).

The first of these critical levels is the Minimum Required Funding Ratio, which determines whether the immediate recovery plan needs to be implemented. We take MRFR = 104.3%, in accordance with existing regulations. When the PFR drops below the MRFR for five consecutive years, an immediate recovery plan is called for. This consists of a reduction in all pension entitlements. The reduction factor is not completely prescribed in the nFTK; we choose a factor such that after the recovery plan, the maximum of the PFR and the actual funding ratio would be equal to the MRFR. So, there is no reduction in pension entitlements when the current PFR is above the MRFR, nor when the current actual funding ratio is above MRFR, while

[3]Actually, the value of 104.3% was chosen more or less arbitrarily (but to some extent reflects the current low values of the funding ratios). Since we work on a long time horizon, the effect of the initial PFR is not likely to be large.

[4]The ten-year averaged term structure is higher than the current term structure. This means that applying cushioning will result in lower pension contributions than without cushioning. From a longer term perspective, also assuming that the past is representative for the future, applying cushioning to determine pension contributions seems plausible.

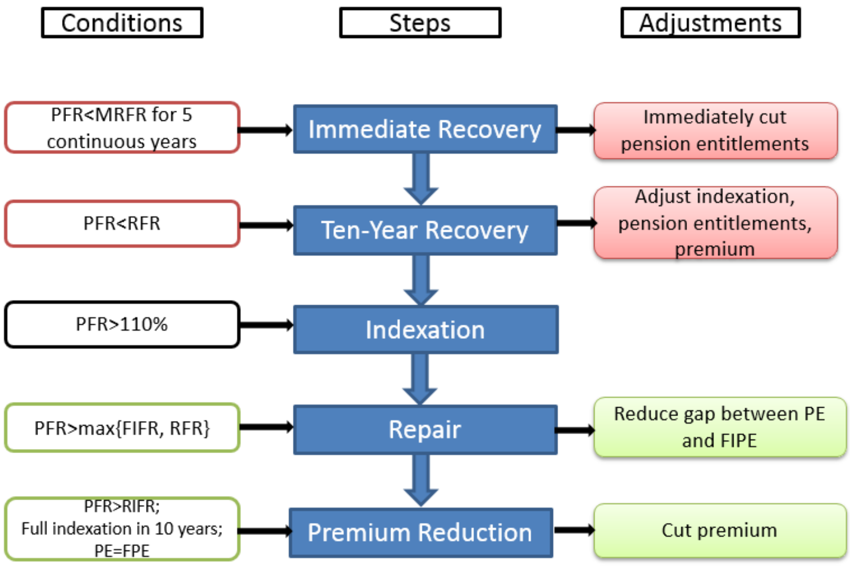


Figure 2.1: At the beginning of each period, the Policy Funding Ratio (PFR) is given. Depending on its value, the pension fund will decide which policies to implement. If the PFR has been below the Minimum Required Funding Ratio (MRFR) for five consecutive years, an immediate recovery plan has to be implemented. In this case, pension entitlements for current and future retirees will be cut immediately. The liabilities will be recomputed given the reduced pension entitlements. If the PFR is below the Required Funding Ratio (RFR), a ten-year recovery plan has to be implemented. The implementation of the ten-year recovery plan guarantees a recovery of at least 10% during the first year. If the PFR is larger than 110%, indexation may be possible. If the PFR exceeds both the RFR and the Full Indexation Funding Ratio (FIFR), then repair policies may be implemented. Finally, pension contribution reductions may be possible when full indexation has been given during ten consecutive years, pension entitlements are equal to the full indexation pension entitlements, and the PFR is larger than the lower bound for pension contribution reductions.

PFR	Policy Funding Ratio
MFR	Minimum Required Funding Ratio
RFR	Required Funding Ratio
IFR	Indexation Funding Ratio (lower bound for indexation)
FIFR	Full Indexation Funding Ratio (lower bound for full indexation)
RIFR	Reduction Indexation Funding Ratio (lower bound for pension contribution reduction)

Table 2.1: Abbreviations

the PFR is below MRFR, as permitted by the nFTK.[5]If neither of these conditions holds, however, pension entitlements will be reduced. If the previous funding ratio is smaller than the MRFR, we choose a reduction factor to bring the current actual funding ratio back to the MRFR; otherwise, we make the PFR equal to the MRFR. The new liabilities and pension entitlements will then replace the old ones in the future calculation and simulation. This results in a lower value for the indexation ratio, since the numerator of this ratio will become smaller, while the denominator remains unaffected.

The second critical level is the Required Funding Ratio. It should be set such that, with a probability of 97.5%, next year's actual funding ratio is at least equal to one. We use its current average value of 126.6% in the simulation, which we assume to remain constant over the fifty-year time horizon. As soon as the PFR is below the RFR, a recovery plan has to be implemented, which should result in the PFR recovering to at least the level of the RFR in no more than ten years, with at least 10% recovery in the first year, using the values of the expected returns and inflation according to the "Advies Commissie Parameters" (Parameters Committee Recommendations, ACP).[6] The ten-year recovery plan includes a series of adjustments which may apply to indexation, pension contributions, and pension entitlements. We choose a plan in which pension contributions are not modified. We first try to find an indexation factor to make the increase in the PFR equal to the desired increase of 10% in the gap between the RFR and the PFR, without any reduction in pension entitlements. If zero indexation by itself is not sufficient, then we supplement this with a reduction factor that will be applied to pension entitlements to increase the PFR by the desired amount. We calculate the required forward rates using the yield curve provided by our model.

The third critical level is the lower bound for indexation, the Indexation Funding Ratio (IFR). Its value is not prescribed in the proposed Pension Act but is subject to lower-level regulation; it has been announced that the IFR will be set at 110%. Partial (but not necessarily full) indexation will only be allowed if the PFR is higher than the IFR. The nFTK framework allows pension funds to use an indexation target in either absolute or relative terms with respect to a given index, such as wage or price inflation. We use a relative indexation target with respect to wage inflation. Since IFR is less than RFR for our stylized fund, the fund could provide indexation, but at

[5]In the latest revision of the law, this rule has been further refined; this modification has not been incorporated into our model; we assume it to have little effect.

[6]See website: `https://www.rijksoverheid.nl/documenten/rapporten/2014/03/21/advies-commissie-parameters`.

the same time it is constrained by the recovery rules. When there are no constraints from recovery, indexation is determined by the rule that after pension payments at the beginning of the period have been made, the resulting funding ratio must be equal to at least the IFR. The funding ratio is computed under the assumptions that indexation is applied to the present and future periods based on expected wage inflation and that liabilities are discounted on the basis of the Expected Return on Stocks (ERS) using the ACP parameter values. The indexation factor is set as high as possible given this rule, but not higher than the current wage inflation. When the fund is in recovery, we use a lower indexation factor, determined by the recovery rules.

The fourth critical level is the lower bound for full indexation (denoted by FIFR for "Full Indexation Funding Ratio"). It is the funding ratio that corresponds to the situation in which full indexation according to expected wage inflation (using the ACP parameter value) is applied to present and future years. This lower bound plays a role when pension entitlements are lower than the fully indexed pension entitlement (i.e., the pension entitlements under the assumption of full indexation and no cuts; see Equation (2.4) in the appendix). If, after indexation, we still have a PFR that exceeds the RFR and the FIFR, repair policies may be implemented. Repair policies are intended to decrease (or even close) the gap between the actual and fully indexed pension entitlements. When the conditions for a repair policy are satisfied, 20% of the excess funds may be used to reduce the gap between pension entitlements and fully indexed pension entitlements. However, the repair should be limited such that the funding ratio after application of the repair policy is still at least as large as the maximum of the RFR and the FIFR.

The fifth and highest critical level is the Reduction Indexation Funding Ratio (RIFR), the lower bound for a reduction in pension contributions set by the pension fund. We set it equal to the RFR. This criterion is relevant for pension contribution reduction policies. When the PFR is at least equal to the lower bound for pension contribution reduction (RIFR), full indexation has taken place in the previous ten years, and pension entitlements are at the same level as the fully indexed pension entitlements for all generations, then there can be an immediate reduction in pension contributions. We continue to use the term-structure-based pension contribution. The pension contribution is reduced to a level under which the resulting funding ratio is equal to RIFR.

2.3 Economic Setting

We want to investigate the performance of the nFTK in different economic situations. To do so, we want to simulate the PFR, indexation ratios, and pension entitlements for a period of fifty years and examine the relationships between the indexation ratio, PFR, asset return, and wage inflation. We use a vector autoregressive (VAR) model to generate economic scenarios and determine the term structure of interest rate. We assume that prices for all of the assets in the economy are determined by a state vector x_t which follows a VAR process in the form of

$$x_{t+1} = \alpha + \Gamma x_t + \Sigma \varepsilon_{t+1} \tag{2.1}$$

where $\varepsilon_{t+1} \overset{i.i.d}{\sim} N(0_{n\times 1}, I_{n\times n})$. We can use the VAR model to generate many future scenarios; for each scenario, a model-based affine term structure can be determined. Our model is a discrete time model, in the spirit of the continuous time model of Koijen, Nijman, and Werker (2010). We use monthly data to estimate the VAR model. Time-to-maturity is measured in half years.

The set of common factors x_t consists of five components ($n = 5$), which are the German annualized zero-coupon federal securities rate with remaining time to maturity of 0.5 years; the Dutch inflation rate; the MSCI world stock return in excess of the six-month rate (i.e., in excess of the first component); the German ten-year zero-coupon federal securities yield spread; and the Dutch nominal wage inflation rate. The six-month rate and the ten-year rate are downloaded from Deutsche Bundesbank.[7] Both series are available from September 1972. The inflation rate is derived from the Netherlands consumer price index, which is obtained from Datastream. Nominal wage inflation is derived from the CAO wage index, also obtained from Datastream. The CAO wage index is available starting from January 1990; consequently, taking into account that time to maturity is measured in half years, wage inflation is available from July 1990. The excess stock return is derived from the MSCI world total return stock index downloaded from Datastream. The MSCI world total return index has been available since 1969. Table 2.2 shows the names and meanings of each variable used in the VAR model; Table 2.3 presents the sample statistics; and Figure 2.2 plots the development of each variable since the initial date.

In the estimation, we only use data from July 1990 to March 2014. First, this is because most variables, such as inflation, the short rate, and the ten-year rate, behaved very differently after the market crash at the end of the 1980s. For instance,

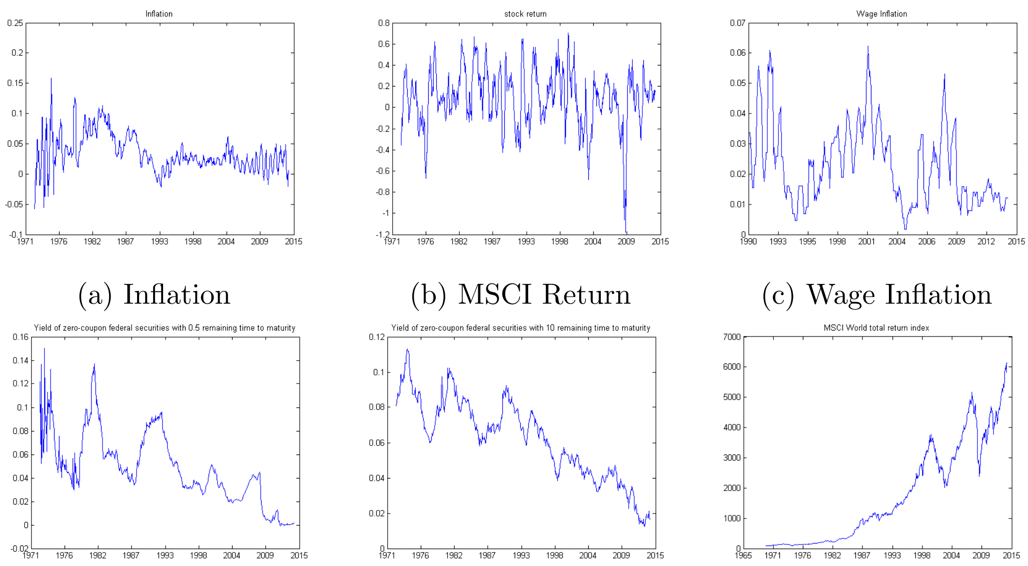
[7] http://www.bundesbank.de/Navigation/EN/Statistics/statistics.html.

Variable Name	Definition
$y^{(1)}$	Annualized six-month zero-coupon federal security rate
cpi	Inflation
$r_s - y^{(1)}$	Stock return premium
$y^{(20)} - y^{(1)}$	Ten-year zero-coupon federal security yield spread
$wage$	Nominal wage inflation

Table 2.2: Symbols and Meanings of Variables

	average	std.dev	minimum	maximum
$y^{(1)}$	3.48%	2.52%	-0.06%	9.63%
cpi	2.20%	1.35%	-2.04%	6.25%
$r^s - y^{(1)}$	2.86%	28.62%	-118.71%	67.41%
$y^{(20)} - y^{(1)}$	1.40%	1.19%	-1.76%	3.59%
$wage$	2.29%	1.30%	0.18%	6.23%

Table 2.3: Sample Statistics for the State Variables



(a) Inflation (b) MSCI Return (c) Wage Inflation

(d) Short Rate (e) Ten-year rate (f) MSCI

Figure 2.2: Historical Data

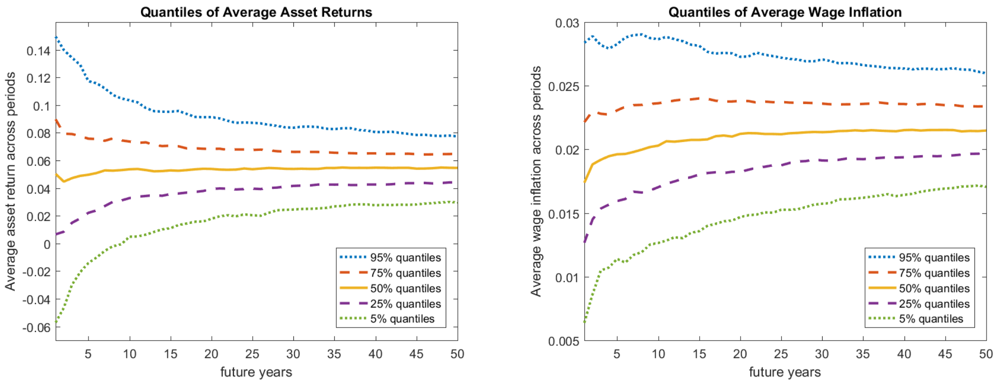
we see in Figure 2.2a that inflation was very volatile in the 1970s and 1980s. The second reason for this is that wage inflation data is only available since July 1990. We use the maximum likelihood method to estimate the coefficients of the VAR model. The estimation results are shown in Table 2.4. Next, we calibrate the price of risk to fit an affine term structure to the observed term structures of interest rates. A detailed description of this calibration can be found in the appendix.

	α	Γ				
$y^{(1)}$	0.0044	0.9602	-0.0237	0.0013	-0.1048	-0.0465
	0.0012	*0.0178*	*0.0259*	*0.0011*	*0.0368*	*0.0298*
cpi	0.0027	0.0006	0.7680	0.0029	-0.0289	0.1194
	0.0018	*0.0255*	*0.0370*	*0.0016*	*0.0526*	*0.0426*
$r_s - y^{(1)}$	0.0269	0.3727	-1.3627	0.8635	0.7079	-0.6779
	0.0321	*0.4638*	*0.6747*	*0.0289*	*0.9587*	*0.7762*
$y^{(20)} - y^{(1)}$	0.0008	-0.0090	-0.0135	-0.0009	0.9698	0.0154
	0.0006	*0.0082*	*0.0120*	*0.0005*	*0.0170*	*0.0138*
wage	0.0059	0.0018	-0.0559	0.0009	-0.1177	0.8672
	0.0013	*0.0194*	*0.0281*	*0.0012*	*0.0400*	*0.0324*

			Σ		
$y^{(1)}$	0.0052	0	0	0	0
cpi	0.0019	0.0072	0	0	0
$r_s - y^{(1)}$	-0.0120	0.0071	0.1356	0	0
$y^{(20)} - y^{(1)}$	-0.0005	0.0001	0.0001	0.0024	0
wage	0.0017	0.0010	-0.0001	0.0005	0.0053

Table 2.4: The VAR model is described by equation (2.1). The variables in the first column are the state variables. In the upper panel of this table, the estimated coefficients of α and Γ are presented, with the corresponding standard errors in italics. In the lower panel of this table the estimated coefficients of Σ are presented.

With the estimated VAR model, we can simulate economic scenarios for future interest rates, stock returns, price inflation, and wage inflation. The starting values of the simulation are the average of the last year's observations. Using the simulated term structures, we can derive the bond returns and discount factors needed for calculating pension liabilities. Given the bond and stock returns, the pension fund's asset returns can be determined as a weighted average of the bond returns and the stock returns, with 65% invested in bonds (i.e., zero-coupon bonds with a maturity of ten years) and 35% in stocks (with returns given by r_s). Assuming the initial wage base is 1, the wage inflation gives us enough information to simulate the wage base



(a) Pension fund's asset returns (b) Nominal wage inflation

Figure 2.3: Quantiles of the pension fund's average annual asset returns (left panel) and average nominal wage inflation (right panel)

for fifty future years, and the full indexation pension entitlements can thus also be determined. The number of workers and number of retirees for each generation are fully determined by the population distribution of the pension fund and the 2014 cohort life table. With this information, we can update the pension assets, liabilities, pension entitlements for each generation, actual funding ratio, and PFR at each period in each path.

To illustrate the model outcomes, Figure 2.3 shows the development over time of the quantiles of two of the main drivers determining outcomes, namely the average (across time) of the pension fund's annual asset returns (Panel [a]) and the average (across time) of the nominal wage inflation (Panel [b]). As the figure shows, in most scenarios the pension fund's average annual asset returns at the time horizon (i.e., fifty years from now) is between 3% and 8%, and the average nominal wage inflation is between 1.6% and 2.6%.

As the main measure of success of a pension scheme, we use the *indexation ratio*[8] in this paper. We define the indexation ratio for a given generation as the ratio of actual pension entitlements (incorporating the cumulative effects of conditional indexation) to fully indexed entitlements, computed cumulatively from the start of a working career.[9] In the case of retired generations, the indexation ratio is defined as the ratio of paid-out benefits with respect to the benefits that would have been received if full indexation had been applied throughout the generation's participation in the

[8]We use this term rather than "pension result" in view of the fact that several different definitions of that notion have been given in the literature.

[9]See Equation (2.5) in the appendix. We exclude negative indexation due to negative wage inflation.

pension scheme. Thus, it is equivalent to the replacement ratio for those generations. Table 2.5 presents, at a time horizon of fifty years from now, the correlations between the indexation ratios of the cohorts in age groups 25, 45, and 67 at the start of the simulation, the PFR, the pension fund's average annual asset returns ("return index", abbreviated RI), and the average wage inflation ("wage").[10] The correlation between the indexation ratios of the different cohorts is close to one, indicating that in the long run, there will only be minor differences between the cohorts in terms of their indexation ratios. There is a positive correlation around 0.51 between the RI and the indexation ratios and a positive correlation around 0.35 between the indexation ratios and the PFR. The correlation between the PFR and the RI is high, around 0.91. We find a negative correlation around -0.21 between wage inflation and the indexation ratios and PFR. Finally, the correlation between the two main drivers, RI and wage inflation, is around -0.09. This negative correlation is of the same order of magnitude as the negative correlation we observe in-sample between the pension fund's annual asset returns and annual wage inflation (where both are not averaged in-sample), namely around -0.14.

Figure 2.4 plots the wage inflation against the RI at the time horizon. The figure includes the conditional 5% quantile, the conditional median, and the conditional mean, the latter together with 95% uniform confidence bands, of the wage inflation, conditional on the return index.[11] As the figure illustrates, the negative correlation of around 0.09 corresponds to a slightly negative linear relationship between the wage base and the RI. This suggests, according to the model outcomes, that the scenarios with a high value of RI are not necessarily the scenarios where a high value is needed for wage indexation, and, similarly, the scenarios with a low value of RI are not necessarily the scenarios with a lower need for wage indexation.

2.4 Evaluation of the nFTK

In this section, we use our stylized pension fund to evaluate the nFTK, taking the contribution and investment policies of the pension fund as given. We focus on the

[10] At the time horizon, the generation whose current age is 67 years does not exist anymore in our model. However, the model allows us to calculate the indexation ratios that would apply to this generation.

[11] More precisely, the figure shows nonparametric Kernel estimates of $\mathrm{Med}(\underline{w}|\underline{r} = r)$, $\mathrm{Quant}_{0.05}(\underline{w}|\underline{r} = r)$, and $E(\underline{w}|\underline{r} = r)$, for different values of r, with $\underline{w}$ standing for the random wage inflation per year and $\underline{r}$ standing for the random return on the index per year, both measured at the time horizon. The estimates are calculated based on the scenarios. The estimates of $E(\underline{w}|\underline{r} = r)$ are supplemented with 95% uniform confidence bands.

Ind 25	Ind 45	Ind 67	PFR	RI	wage
1	99.3%	99.2%	35.3%	50.5%	−21.0%
99.3%	1	100.0%	35.4%	50.9%	−20.7%
99.2%	100.0%	1	35.3%	50.9%	−20.7%
35.3%	35.4%	35.3%	1	90.7%	−21.1%
50.5%	50.9%	50.9%	90.7%	1	−9.3%
−21.0%	−20.7%	−20.7%	−21.1%	−9.3%	1

Table 2.5: The correlation matrix at the time horizon is shown for the indexation ratios of the current 25-year-olds (Ind 25), 45-year-olds (Ind 45), and 67-year-olds (Ind 67), the policy funding ratio (PFR), the pension fund's average annual asset returns ("return index", abbreviated RI), and the average wage inflation ("wage"). The table is based on all paths at the fifty-year horizon.

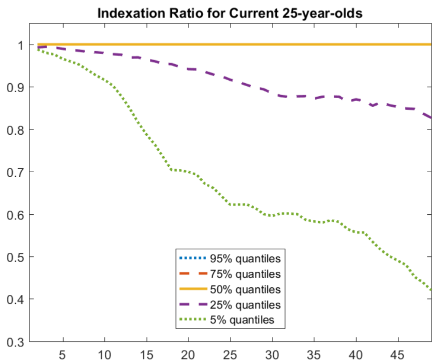
Figure 2.4: Wage inflation in relation to the pension fund's asset return.

pension fund's real ambition, which we assume to be reflected in fully indexed pension entitlements. The actual pension entitlements might be less than the fully indexed entitlements. Therefore, we quantify the real ambition in terms of the indexation ratio, which we define as the ratio of the actual pension entitlements to the fully indexed pension entitlements (see previous section). We take a long-term perspective, a time horizon of fifty years. We investigate to what extent the pension fund will be able to fulfill its real ambition at the time horizon, and, if so, whether this ambition can be fulfilled without overfunding. We use the economic setting described in the previous section. In particular, we assume that pension contributions will be kept constant, even under less favorable circumstances, and we assume that the pension fund's asset portfolio composition (i.e., 65% bonds and 35% stock) will also be kept constant over time, irrespective of the economic circumstances. Our study therefore shows the effects of the regulatory framework on a pension fund that follows such a relatively simple policy.

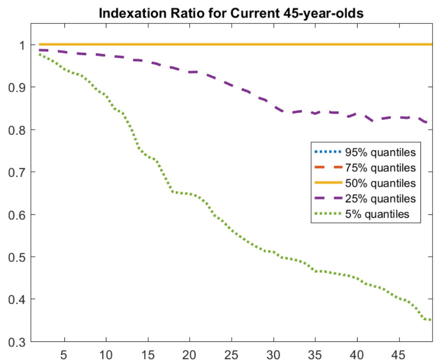
Figures 2.5 shows the development over time of the quantiles of the resulting indexation ratios for the three age cohorts 25-years-old (Panel [a]), 45-years-old (Panel [b]), and 67-years-old (Panel [c]) at the start of the simulations.[12] Figure 2.6 shows the corresponding quantiles of the resulting evolution of the PFR up to the time horizon. Table 2.6 gives the exact percentages of underfunding and overfunding at various horizons. In the last column of Table 2.6, we also present the percentages of the simulations in which the indexation ratios for all generations still alive are equal to one for different future years.

The movement of the 5% and 95% quantile of Figure 2.6 shows that the downside of the PFR is quite stable but the upside can soar up to more than 700% in fifty years. It reflects the asymmetry of the system design. When the PFR is very low, an immediate cut in the pension entitlements will bring the PFR back, resulting in a stable PFR in the downside. When the PFR is very high, however, many criteria have to be met to give full indexation, raise pension entitlement, and cut contributions. The pension fund is restricted in the possibilities to share the built up wealth with the pension participants. As a consequence, wealth is shifted to the future indefinitely. The wealthy pension fund also benefits from our assumptions of the term structure and the asset returns. The average term structure of interest rates generated from our model is higher than the current term structure. As shown in Figure 2.7, the PFR is positively related to the interest rates. However, the effect of interest rate on the PFR is not as large as one might think. For instance, the PFR in the median

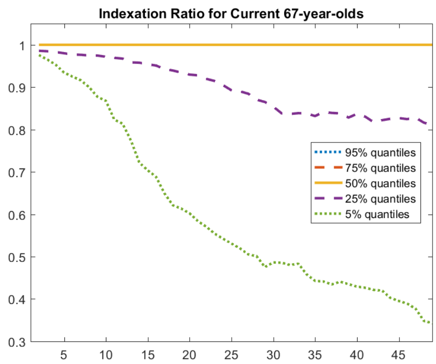
[12]See Footnote 10.



(a) Current 25-year-olds.



(b) Current 45-year-olds.



(c) Current 67-year-olds.

Figure 2.5: Quantiles of the indexation ratios of the current 25-year-olds (Panel [a]), 45-year-olds (Panel [b]), and 67-year-olds (Panel [c]).

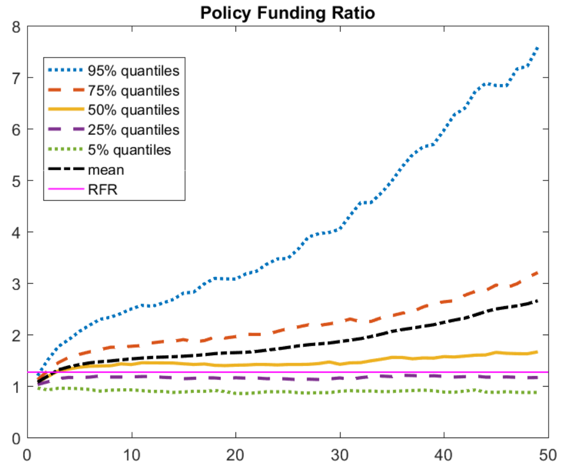


Figure 2.6: Quantiles of the Policy Funding Ratio (PFR).

case only increases by around 0.13 if the one-year rate increases from 0% to 2%. As shown in Figure 2.10, the PFR is positively related to the asset return, as well. To achieve the RFR in the median case, an asset return of 4.5% is required. Panel [a] of Figure 2.3 shows that the median asset return is more than 5% in our model.

The 5% quantile in Panel (a) of Figure 2.5 shows that the indexation ratio for the generation whose current age is 25 can decrease to less than 50% at around retirement age in at least 5% of the scenarios. Similarly, the 5% quantiles of Panels (b) and (c) of Figure 2.5 show that the indexation ratio for the generation whose current age is 45 or 67 can decrease to less than 50% within between 25 to 30 years in at least 5% of the scenarios. Such low indexation ratios are a result of less-than-full indexation and pension entitlement cuts, under the assumptions (which we make) that pension contributions are kept constant even under less favorable circumstances and the pension fund's asset portfolio composition is kept constant over time.

In the median case, the indexation ratio equals one in all three cases. In fact, full indexation at the end of the simulations occurs in close to 60% of the scenarios (see last column of Table 2.6), which also means that in around 40% of the scenarios, the real ambition of an indexation ratio equal to one is not achieved. To clarify the outcomes, we present in Figures 2.8 and 2.9 the indexation ratios for the cohorts of current 25-year-olds (Panel (a)) and current 45-year-olds (Panel (b)) at the time horizon in relation to the PFR (Figure 2.8) and the pension fund's average annual asset returns (Figure 2.9).[13] The figures include the conditional 5% quantile, the condi-

[13]We do not include the graph for the current 67-year-olds since that generation will no longer exist in our model at the time horizon. See also Footnote 10.

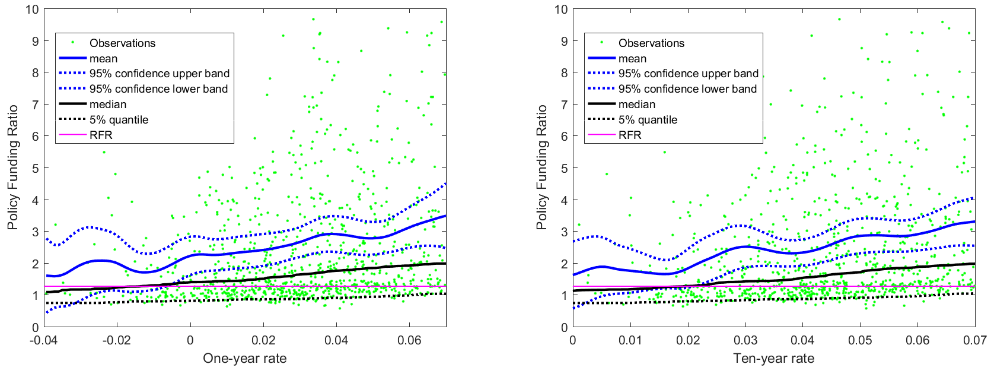
Year	PFR<100%	PFR<104.3%	PFR>110%	PFR>126.66%	PFR>150%	Full Ind. Ratio
1	15.1%	34.4%	34.2%	0.9%	0.0%	-
2	12.5%	17.7%	71.4%	30.4%	5.4%	58.5%
3	8.3%	12.3%	80.9%	54.2%	19.7%	59.1%
4	8.1%	12.0%	82.9%	58.6%	29.8%	61.5%
5	8.8%	12.2%	82.1%	62.4%	34.9%	61.9%
10	9.3%	12.3%	82.8%	64.7%	43.2%	63.4%
15	12.7%	15.7%	78.8%	63.0%	44.4%	63.4%
20	12.5%	15.6%	80.2%	63.4%	43.1%	57.7%
25	11.0%	14.4%	79.1%	62.5%	45.7%	56.9%
30	11.2%	15.8%	79.3%	63.2%	46.2%	57.7%
35	9.9%	12.3%	82.9%	67.3%	51.8%	58.6%
40	10.5%	13.7%	81.7%	67.4%	52.7%	60.0%
45	11.4%	13.4%	80.2%	65.9%	53.3%	59.8%
49	12.2%	15.0%	79.0%	66.7%	53.6%	60.7%

Table 2.6: We summarize the probability of the Policy Funding Ratio (PFR) being below 100%, below the Minimum Required Funding Ratio (MRFR), above the lower bound for indexation, above the Required Funding Ratio (RFR), and above 150% at various horizons. The probability of full indexation is given as well. Both the pension entitlements and the fully indexed pension entitlements start at the same level, so the indexation ratio is not relevant for the first year.

tional median, and the conditional mean, where the last variable is also accompanied by a 95% uniform confidence band. The vertical line indicates the RFR. These figures are constructed analogously to Figure 2.4.

As these figures show, given a PFR that is approximately the same as the RFR, the indexation ratio will be around 95% or more in 50% of the scenarios (according to the estimated conditional median); the average indexation ratio will be just below 80%; and the indexation ratio can be as low as 35% in 5% of the scenarios (according to the estimated conditional 5% quantile). Thus, based on the worst 5% of cases, we find that a value of the PFR equal to the RFR at the time horizon of fifty years is no guarantee that the pension fund will be able to fulfill its real ambitions. It is highly likely that under such poor conditions, with indexation ratios dropping to 35%, there will be mounting pressure for changes in the system.

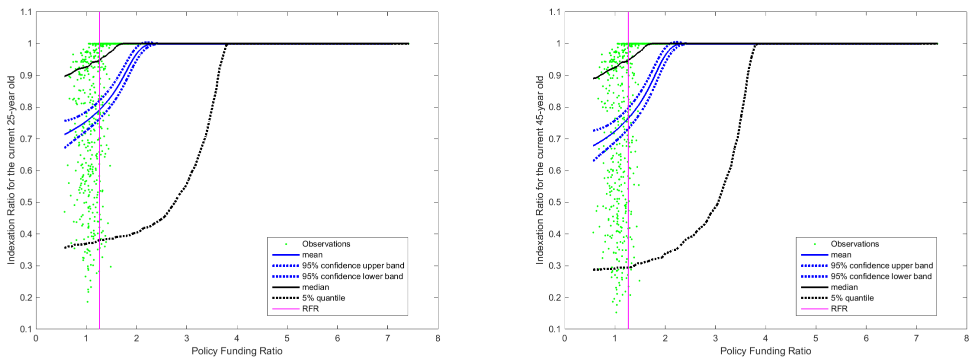
On the other hand, circumstances under which the PFR is close to 400% or the pension fund's average annual asset return is around 7% will result in full indexation in at least 95% of the scenarios (according to the estimated conditional 5% quantiles). To achieve full indexation in at least 50% of the scenarios, a PFR of close to 200% or average annual asset return of close to 5% seems to be required (according to the estimated conditional medians). Thus, under favorable conditions (average



(a) One-year rate

(b) Ten-year rate

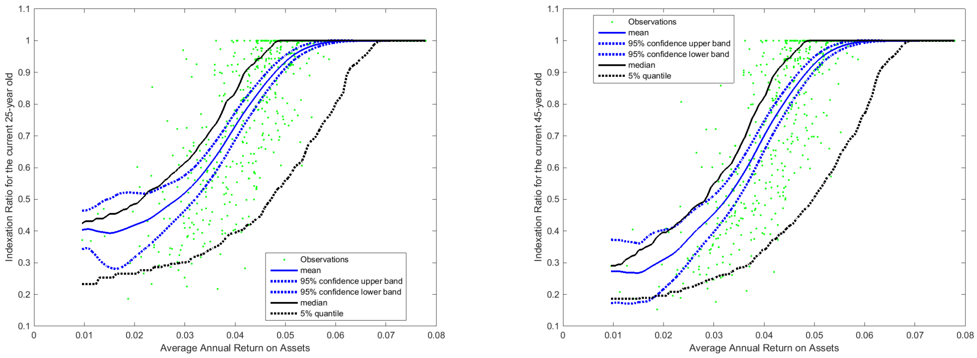
Figure 2.7: Policy Funding Ratio in relation to the one-year rate (Panel [a]) and ten-year rate (Panel [b]), measured at the time horizon.



(a) Current 25-year-olds

(b) Current 45-year-olds

Figure 2.8: Indexation ratios for current 25-year-olds (Panel [a]) and 45-year-olds (Panel [b]) in relation to the Policy Funding Ratio (PFR), measured at the time horizon. The vertical line indicates the Required Funding Ratio (RFR).



(a) Current 25-year-olds (b) Current 45-year-olds

Figure 2.9: Indexation ratios for current 25-year-olds (Panel [a]) and 45-year-olds (Panel [b]) in relation to the pension fund's average annual returns, measured at the time horizon.

annual asset return of around 7% or more), the pension fund is able to fulfill its real ambitions (at the time horizon) to a large extent. But given the current nFTK, such favorable conditions will likely result in PFRs far above the RFR. This is confirmed by Figure 2.10, which shows the conditional 5% quantile, the conditional median, and the conditional mean (accompanied by a 95% uniform confidence band) of the PFR measured at the time horizon, conditional on the pension fund's average annual asset returns.[14] The horizontal line in this figure represents the RFR. As the figure shows, given an average annual asset return of around 7%, the PFR will be over 325% in 50% of the scenarios (according the conditional median estimates). Such high PFRs are achieved by taking into account the pension contribution reduction policies under the nFTK (but also assuming no change in the composition of the pension fund's asset portfolio over time). Therefore, there will be pressure for changes of the system even under favorable circumstances. We have assumed a fixed investment mix here; if the nFTK is sustained, this assumption is not likely to remain valid. However, it is nevertheless likely that under such circumstances, the regulatory system will also be under pressure to allow more benefits to be paid to current generations.

Our model therefore indicates that in both bad-weather and good-weather scenarios, it is likely that the nFTK will not be sustained. We should point out, however, that the predicted effect may be due in part to limitations in the model in combination with the available data. Figure 2.4 shows that the negative correlation between the pension fund's average annual asset return and average wage inflation in our model

[14]The qualitative nature of this figure might not come as a surprise; we include this figure because of its quantitative information.

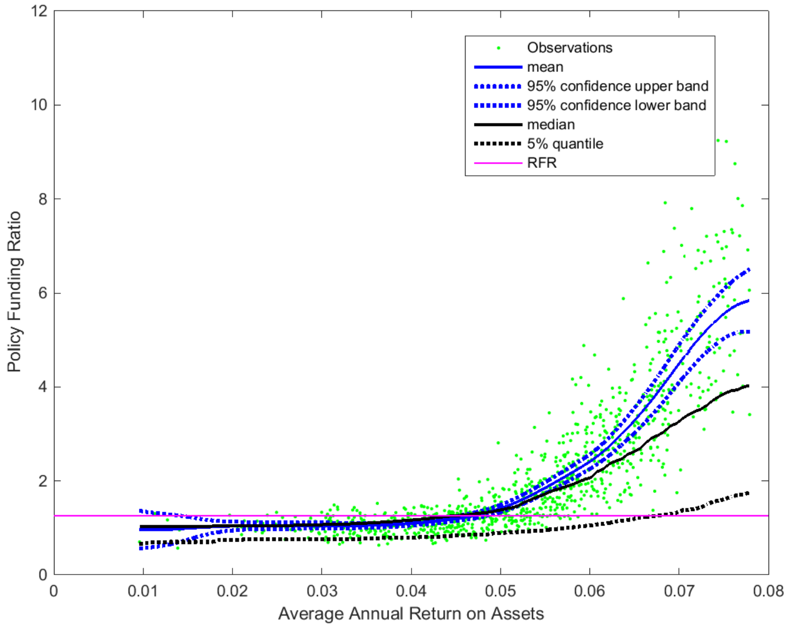


Figure 2.10: The Policy Funding Ratio (PFR) in relation to the pension fund's average annual returns, measured at the time horizon. The horizontal line indicates the Required Funding Ratio (RFR).

corresponds to a slightly downward sloping line when the average wage inflation is considered in relation to the average annual asset return. This means that in our model, the pension fund's asset return does not hedge against wage inflation. The negative correlation in our model between the pension fund's average annual asset return and average wage inflation is in line with the observed in-sample correlation between annual wage inflation and annual asset return (equal to around -0.14). However, the actual relationship between average wage inflation and average annual asset return may be nonlinear, as indicated by Figure 2.11.This figure shows the conditional 5% quantile, the conditional median, and the conditional mean (accompanied by a 95% uniform confidence band) of the in-sample annual wage inflation in relation to the in-sample pension fund's annual asset returns. The relationship between annual wage inflation and the in-sample pension fund's annual asset returns appears to be nonlinear, with a more or less unclear pattern for annual returns of less than -15% (due to a lack of observations), followed by a more or less clear U-shaped pattern for annual returns above -15%.[15] If there is a positive correlation between asset returns and wage inflation in scenarios with either very good or very bad returns, then the

[15]As reported, this nonlinear relationship corresponds to a linear correlation of around -0.14.

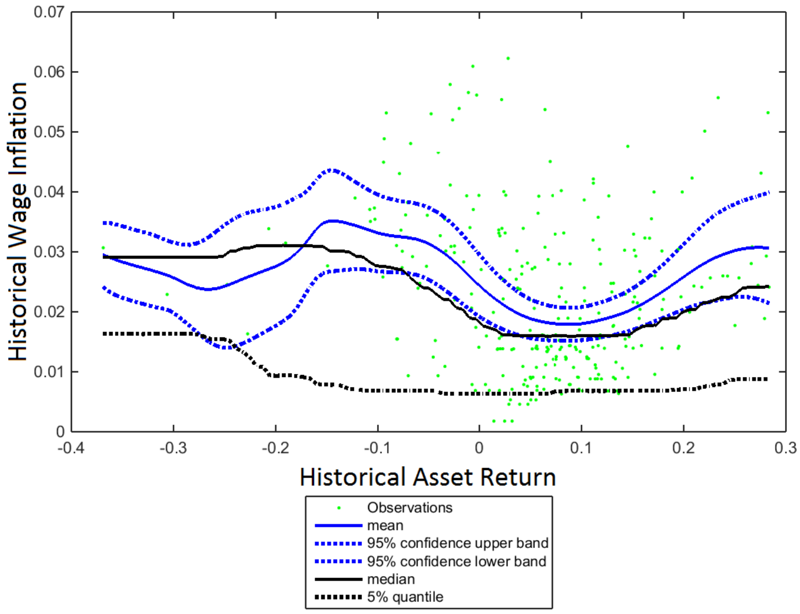


Figure 2.11: The in-sample annual wage inflation in relation to the in-sample pension fund's annual asset return.

large spread of outcomes that we get from our model would be mitigated. However, to capture a relationship as presented in Figure 2.11 requires a more flexible, and likely heavily nonlinear, model, which is beyond the scope of this paper.[16]

2.5 Some Design Issues

We consider a stylized pension fund with a fixed investment and contribution policy (but where the contributions will be lowered if allowed by the nFTK rules). Given this set-up, the policy funding ratios turn out to be high in many scenarios within the set generated by our economic model. After five years, the probability of the PFR exceeding 150% is around 35%; the median PFR goes over 150% after 35 years; and the 95% quantile soars to more than 700% at the end of the simulation period. The occurrence of such unrealistically high funding ratios is due to the restrictions that are placed on recovery indexation and pension contribution reductions, in combination with the assumptions that are built into our economic model.[17] Given that expected

[16]Moreover, more flexible nonlinear models might improve the in-sample fit but typically perform rather poorly out-of-sample due to the possibility of overfitting.

[17]In the revision of the Pension Act as originally proposed by the Dutch government, the amount that could be used for recovery indexation was maximized to 10% of the surplus. Parliament adopted

asset returns exceed wage inflation, funding ratios may still reach high levels even under full indexation; the additional instrument of reducing pension contributions can only be applied under very restrictive assumptions within the nFTK.

In spite of the high median funding ratio produced in our scenario set, the probability of less than full indexation is substantial, even after fifty years. This indicates that under the nFTK, pension fund participants cannot always take full advantage of favorable economic circumstances. In the set of scenarios corresponding to less than full indexation, realized funding ratios are distributed more or less evenly across a wide spectrum of outcomes. As can be expected, low indexation ratios tend to be associated with scenarios under which there are low asset returns and/or high wage inflation. The 5% quantile corresponds to policy funding ratios that go down to almost 40%. It appears that, for a fund that maintains a fixed-mix investment policy, the nFTK system neither provides an effective cap on fund wealth nor protects pensions against adverse economic scenarios. Under such circumstances, the system is not expected to be maintained. The goal of providing a sustainable, future-proof system seems too ambitious to be achieved by the current design of the nFTK in itself. There is a "catch" in the system: full indexation occurs mainly in scenarios in which the funding ratio is at levels that are likely to lead to changes in the system. At the same time, under adverse scenarios, indexation ratios may drop dramatically. The system is not symmetric on the upper and lower sides. It is slower to give indexation on the upper side than to cut pension entitlements on the lower side, which can result in the "catch" and cause instability in the form of a very high PFR. The system has a tendency to shift wealth to the future. In that sense, it is unfair to the participants since the value of what they get could be less than what they pay for. However, further investigation is needed to judge the fairness of the system.

We do some sensitivity analysis on the asset mix, the initial funding ratio, and parameter values to see how robust the results are to those changes. Increasing the asset allocation to stocks does not help to improve the results. Changing the asset mix to 45% in stocks and 55% in long-term bonds results in an even higher PFR on the upper side and an even lower indexation ratio on the lower side. After 50 years, the PFR can soar to 1200% at the 95% quantile while the indexation ratio of the current 25-year-olds can drop to 36% at the 5% quantile. Under the nFTK, with a fixed asset mix, it is better for the participants to have a conservative investment policy. The system is reluctant to give indexation when there are gains from the investment,

an amendment which raised the maximum to 20%. In our calculations, we have applied the latter policy; however, the differences with the outcomes under the rule originally proposed are small.

but an investment loss will be borne by the pension participants via cuts in pension entitlements. A much lower initial funding ratio of 95% decreases the frequency of full indexation and its effect is stronger for short periods than for long periods. Full indexation is achieved in about 40% of the scenarios in the beginning years, and at the time horizon of fifty-year, it is achieved in 56.1% of the scenarios.

The results could possibly be improved by adapting some of the parameters of the nFTK regulatory framework. For example, changing the conditions for the repair policy, such that 100% of the funds in excess of the RFR could be used to reduce the gap between actual and full indexed pension entitlements, would increase the probability of full indexation at a ten-year horizon from 63.4% to 66.7%, while the probability of underfunding at the same time horizon would only increase from 12.3% to 12.8%. Coupling such a change in the repair policy with replacing the ACP parameter values by the model-based parameters (e.g., increasing the expected stock returns from 6.75% to 7.5%) would increase the probability of full indexation at a ten-year horizon even further, to 69.2%, while the probability of underfunding at the same time horizon would increase only to 12.9%.

Alternatively, adopting investment policies that are more responsive to economic conditions than the fixed investment mix we created as a benchmark could help avoid the catch referred to earlier. More fundamental improvements, on both the upside and the downside, could be derived from introducing greater flexibility into the policies. Some interesting possibilities for investigation, as topics of future research, could be indexation policies that differentiate between generations or contribution-reduction policies that are more flexible and tied to, for instance, the PFR level.

2.6 Conclusion

In this paper, we investigate the stability of the nFTK based on simulations. We start by establishing a stylized pension fund that mimics the actual demographic structure of the Netherlands. New workers enter into the pension fund at the age of 25 and retire at the age of 67. We assume mortality according to the 2014 life table provided by the actuarial association of the Netherlands. The influx of workers is assumed to be constant. The contributions per individual as a fraction of the pension base are determined at the start of the simulations and assumed to be constant over time, except when a reduction according to the nFTK is permitted. The pension fund's investment policy is a simple fixed-mix policy, 35% in stocks and 65% in ten-year bonds. Pension liabilities are discounted according to the term structure constructed by our own model.

Next, we formalize the nFTK and the various actions that must be taken under different circumstances. We study how the stylized pension fund performs under the nFTK under different simulated economic scenarios. In particular, we investigate the evolution of the indexation ratio and the policy funding ratio of the pension fund in relation to each other and to wage inflation and asset returns. We find that the highly ambitious goal of providing a sustainable, future-proof system seems too great to be achieved by the current design of the nFTK alone, at least given our stylized pension fund and the investment, contribution, and benefits policies considered.

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2.7 Technical Appendix

2.7.1 Introduction

This appendix provides the relevant background information to this chapter. Section 2.7.2 contains a detailed discussion of our implementation of the nFTK, including the choices we made when implementing the nFTK. Section 2.7.3 provides additional information on the economic setting that is used to generate our scenarios.

2.7.2 Stylized Pension Fund and Implementation of the nFTK

In this section we first introduce some notation and we present the set-up of our stylized pension fund in Subsection 2.7.2.1. In Subsection 2.7.2.2 we discuss the premium policies. Subsections 2.7.2.3 and 2.7.2.4 deal with recovery policies in case the funding ratio turns out to be too low. In Subsection 2.7.2.5 we present the indexation policies. In Subsection 2.7.2.6 we then discuss repair policies, followed by pension contribution reduction policies in Subsection 2.7.2.7.

2.7.2.1 Notation and Set-Up

Time is denoted by t. A generation g is referred to by the superscript (g). We assume that in each period t a new generation $g = t$ enters. At the start of time t there are $N_t^{(g)}$ individuals of generation g. Survival probabilities at time t of generation g are denoted by ${}_\tau p_t^{(g)}$, with τ the number of survival periods. Starting from $N_g^{(g)}$ (given exogenously), we assume $N_{t+1}^{(g)} = p_t^{(g)} N_t^{(g)}$, with $p_t^{(g)} \equiv {}_1p_t^{(g)}$. Time to retirement of generation g at the start of time $t \geq g$ is denoted by $T_t^{(g)}$. We have $T_g^{(g)} = T_g$, with T_g denoting the time to retirement when generation g enters the pension fund, and $T_t^{(g)} = T_{t-1}^{(g)} - 1$ for $t \geq g+1$. We define the generations paying pension contributions at time t by G_t^0, i.e.,

$$G_t^0 = \left\{ g \leq t \middle| T_t^{(g)} > 0 \right\},$$

and the generations receiving pensions at time t by G_t^1, i.e.,

$$G_t^1 = \left\{ g \leq t \middle| T_t^{(g)} \leq 0 \right\},$$

The pension base of generation g at the end of period t is denoted by $W_t^{(g)}$. It is the wage minus the franchise. We assume that $W_g^{(g)}$ is given exogenously, and that

$$W_t^{(g)} = W_{t-1}^{(g)}(1 + WI_t^{(g)}), \qquad g < t \leq g + T_g, \tag{2.2a}$$

$$W_t^{(g)} = 0, \qquad t > g + T_g, \tag{2.2b}$$

where $WI_t^{(g)}$ denotes the relative increase of the pension base of generation g at time t.

Each period t the pension fund has to set the pension contribution c_t and the indexation factor I_t. The pension contribution has to be paid by generations $g \in G_t^0$ as a fraction c_t of $W_t^{(g)}$ at the end of period t. The total contribution is denoted by C_t, and is given by

$$C_t = \sum_{g \in G_t^0} N_t^{(g)} \times c_t W_t^{(g)}.$$

We shall focus on wage indexation. Let WI_t denote the actual wage inflation during period t (averaged over the generations). The indexation is set equal to $I_t = 1 + x_t WI_t$, where $x_t \in [0, 1]$, depending on the circumstances. We set $x_t = 0$ in case $WI_t < 0$.

The indexation factor I_t determines the dynamic evolution of $PE_t^{(g)}$, the (actual) pension entitlements at the beginning of period $t \geq g + 1$, as follows

$$PE_t^{(g)} = \begin{cases} PE_{t-1}^{(g)} \times I_{t-1} + a_{t-1} W_{t-1}^{(g)}, & \text{if } t \leq g + T_g \\ PE_{t-1}^{(g)} \times I_{t-1}, & \text{if } t > g + T_g \end{cases} \tag{2.3}$$

starting at $PE_g^{(g)} = a_t W_g^{(g)}$, where a_t stands for the pension entitlements, as a fraction of the pension base, built up during period t.

Given the actual pension entitlements, $PE_t^{(g)}$, the pension payments, paid at the beginning of the period to the generations $g \in G_t^1$, and denoted by P_t, are equal to

$$P_t = \sum_{g \in G_t^1} N_t^{(g)} \times PE_t^{(g)}.$$

In addition to the actual pension entitlements $PE_t^{(g)}$, we will also keep track of $FIPE_t$, the pension entitlements corresponding to full indexation, where full indexation will be denoted by FI_t (with $FI_t \geq I_t$):

$$FIPE_t^{(g)} = \begin{cases} FIPE_{t-1}^{(g)} \times FI_{t-1} + a_{t-1} W_{t-1}^{(g)}, & \text{if } t \leq g + 42 \\ FIPE_{t-1}^{(g)} \times FI_{t-1}, & \text{if } t > g + 42 \end{cases} \tag{2.4}$$

for $t \geq g + 1$, starting at $FIPE_g^{(g)} = a_t W_g^{(g)}$. In case $PE_t^{(g)} < FIPE_t^{(g)}$ repair policies might be implemented (under strict conditions) to reduce or close the gap between $PE_t^{(g)}$ and $FIPE_t^{(g)}$, see Repair Policies. We set $FI_t = 1 + \max\{0, WI_t\}$.

The indexation ratio $IR_t^{(g)}$ for generation g at time t is defined as:

$$IR_t^{(g)} = \frac{PE_t^{(g)}}{FIPE_t^{(g)}}. \tag{2.5}$$

We denote the time t return on the pension plan's assets by R_t. Then the time t (pension plan's) assets A_t at the beginning of period t (before period t's pension payments) are given by

$$A_t = (1 + R_t)\,(A_{t-1} - P_{t-1}) + C_{t-1}.$$

To be able to determine the (pension plan's) liabilities, we first need to introduce discount factors. Discount factors at the start of time t, discounting τ periods ahead back to time t, are of the form

$$D^{(\tau)}_{m,t} = 1/\left(1 + d^{(\tau)}_{m,t}\right)^{\tau}, \tag{2.6}$$

where $m \in \{a, p, i, \cdots\}$ refers to the method used. For $m = a$, we discount using the actual term structure, i.e., $d^{(\tau)}_{a,t} = R^{(\tau)}_t$, the τ-periods zero coupon yield at time t (also taking into account the prescriptions of the "Committee UFR"). The discount factors corresponding to $m = p$ (see Premium Policies) and $m = i$ (see Indexation Policies) will be introduced later. The (pension plan's) liabilities L_t, determined at the beginning of period t before period t's pension payments, are now defined as follows:

$$L_t = P_t + \sum_{g \le t} \sum_{\tau = \max\{1, T^{(g)}_t\}}^{\infty} {}_{\tau}p^{(g)}_t \times N^{(g)}_t \times D^{(\tau)}_{a,t} \times PE^{(g)}_t. \tag{2.7}$$

The funding ratio FR_t (at the beginning of time t) is defined as $FR_t = A_t/L_t$ (i.e., the ratio of the pension plan's assets and liabilities). The "Policy Funding Ratio" is defined as the 12-months moving average, which we shall approximate by the M-periods moving average funding ratio PFR_t, given by

$$PFR_t = \frac{1}{M} \sum_{\tau=0}^{M-1} FR_{t-\tau},$$

where M represents a period of one year. Since FR_t is measured annually in our simulation, PFR_t is the average of FR_t and FR_{t-1}. Thus, $M = 2$ in our simulation.

There are (at least) five critical points for PFR_t. First, RFR_t denotes the Required Funding Ratio at time t. It should be set such that with probability 0.975 next year's actual funding ratio is at least one. Second, $MRFR_t$ denotes the Minimal Required Funding Ratio at time t. As soon as PFR_t is below RFR_t, a recovery plan has to be implemented, which should result in a recovery of the Policy Funding Ratio to at least the level of the Required Funding Ratio in at most ten years, with at least 10% recovery in the first year. Moreover, as soon as PFR_t is below $MRFR_t$ during $\overline{M}$ periods, where $\overline{M}$ represents five years, immediate action has to be taken to ensure that the actual or the Policy Funding Ratio is at least the Minimal Required Funding Ratio (i.e., $\max\{FR_t, PFR_t\} \geq MRFR_t$). See Recovery Policies for further details. The third critical point is IFR_t, the time t lower bound for indexation. Only if PFR_t is larger than IFR_t, (at least partial) indexation is allowed. See Indexation Policies for further details. The fourth critical point is $FIFR_t$, the time t lower bound corresponding to full indexation. This lower bound plays a role when repairing the wage base ($PE_t^{(g)} < FIPE_t^{(g)}$)), see Repair Policies. The fifth critical point is $RIFR_t$, the time t lower bound of the funding ratio above which pension contributions below the cost-neutral contribution are allowed, see Premium Reduction Policies[18].

Our choices: We set $RFR_t = 1.266$ for all t. This is its current *average* value. In addition, we have $MRFR_t = 1.043$ (the value set by European regulations) and $IFR_t = 1.1$ for all t. For $FIFR_t$, see Repair Policies. We set $RIFR_t = RFR_t$, see Premium Reduction Policies. The demographic structure of the pension plan starts from the Dutch demographic structure in 2009. The inflow of newborns is set constant and equal to the inflow of newborns in 2009. We use the 2014 life tables provided by the Actuarial Society. New generations enter at age 25 with retirement age set at 67, so that $T_g = 42$. The initial wage base $W_g^{(g)}$ is set equal to 1. We use $a_t = 0.01875 \approx 0.7/37$, constant over time. If T denotes the starting period of our simulations, then, if $g \leq T$, we set $PE_T^{(g)} = FIPE_T^{(g)} = (T - g + 1)a_T W_T^{(g)}$, with $W_T^{(g)} = 1$. The pension fund's initial asset value at the start of the simulations (time T) is set equal to $MRF \times L_T$. The zero coupon yield curve ($R_t^{(\tau)}$) and the wage index $WI_t^{(g)} = WI_t$ (the same for all generations) follow from our model. Because our simulations are on an annual basis, we set $PFR_t = \frac{1}{2}(FR_{t-1} + FR_t)$.

2.7.2.2 Premium Policies

In this section we discuss the premium policies, determining the pension contribution c_t that generates a cost-neutral contribution. This premium c_t consists of a basis premium bp_t raised by an extra premium π_t. The basis premium bp_t is set by the regulator as the actuarially required premium for the purchase of new pension obligations (in terms of the nominal pension aspiration a_t, without taking into account future indexation). The extra premium $\pi_t \geq 0$ depends on the chosen way of calculating the premium. The actual premium may be different from the premium $bp_t + \pi_t$, but only if it is larger, or if it turns out that $\pi_t = 0$, and a premium reduction below

[18]We carry out the analysis based on the regulations from December 2014

bp_t might become possible (under strict conditions). For the latter case, see Premium Reduction Policies.

The total amount of premiums received during period t should suffice to pay off the corresponding built up pension rights. Therefore, the basis premium bp_t is set such that

$$\sum_{g \in G_t^0} \left(N_t^{(g)} \times bp_t W_t^{(g)} - \sum_{\tau = T_t^{(g)}}^{\infty} {}_\tau p_t^{(g)} \times N_t^{(g)} \times D_{p,t}^{(\tau)} \times a_t W_t^{(g)} \right) \geq 0,$$

with $D_{p,t}^{(\tau)}$ the corresponding discount factor (to be discussed below). We shall assume that bp_t is set such that we have an equality, i.e.,

$$bp_t = a_t \times \frac{\sum_{g \in G_t^0} \sum_{\tau = T_t^{(g)}}^{\infty} {}_\tau p_t^{(g)} \times N_t^{(g)} \times D_{p,t}^{(\tau)} \times W_t^{(g)}}{\sum_{g \in G_t^0} N_t^{(g)} \times W_t^{(g)}}. \tag{2.8}$$

With respect to the discount factor $D_{p,t}^{(\tau)} = 1/(1 + d_{p,t}^{(\tau)})^\tau$ there are two basis choices for $d_{p,t}^{(\tau)}$. The first one is just $d_{a,t}^{(\tau)}$, the actual term structure of interest rates. The second one is the pension fund's expected return ER_t. In both cases cushioning (in volatility, terminology DNB) is also allowed, i.e., one may use a moving average using past observations (over maximum recent 10 years) or one may use an expectation of the future value (according to the CP). Thus, there are at least four possibilities for $d_{p,t}^{(\tau)}$, in addition to $d_{a,t}^{(\tau)}$ and ER_t:

- $d_{p,t}^{(\tau)} = \frac{1}{\widetilde{M}} \sum_{k=0}^{\widetilde{M}-1} d_{a,t-k}^{(\tau)}$, the $\widetilde{M}$-periods moving average interest rate (where $\widetilde{M}$ represents (at most) 10 years. With monthly data, $\widetilde{M} = 120$.);
- $d_{p,t}^{(\tau)} = d_{a,t}^{CP,(\tau)}$, the expected term structure using the parameter values set by the CP;
- $d_{p,t}^{(\tau)} = \frac{1}{\widetilde{M}} \sum_{k=0}^{\widetilde{M}-1} ER_{t-k}^{(\tau)}$, the $\widetilde{M}$-periods moving average expected returns;
- $d_{p,t}^{(\tau)} = ER_t^{CP}$, the expected return determined using the parameter values set by the CP.

There are some debates going on regarding the discount factor (see, for example, Nijman et al. 2006, Novy-Marx and Rauh, 2009). However, it is not the purpose of this paper to analyze the discounting method. We shall refer to the premiums in the first case, when $d_{p,t}^{(\tau)}$ is based on $d_{a,t}^{(\tau)}$, as the *term structure based premiums*, and we shall refer to the premiums in the second case, when $d_{p,t}^{(\tau)}$ is based on ER_t, as the *expected return premiums*.

For cushioned term structure based premiums, π_t should be set such that

$$\frac{\sum_{g\in G_t^0} N_t^{(g)} \times (bp_t + \pi_t) W_t^{(g)}}{\sum_{g\in G_t^0} \sum_{\tau=T_t^{(g)}}^{\infty} {}_\tau p_t^{(g)} \times N_t^{(g)} \times D_{p,t}^{(\tau)} \times a_t W_t^{(g)}} \geq RFR_t,$$

or, using bp_t as given by (2.8), we find $\pi_t \geq (RFR_t - 1) \times bp_t$. Thus, the term structure based premium is set to $c_t = bp_t + \pi_t \geq RFR_t \times bp_t$ to ensure that the funding ratio that would result from the generated assets and the corresponding liabilities, built up during period t, is at least equal to RFR_t. In other words, the lower bound on π_t should generate sufficient extra funds for future indexation (in addition to maintaining a sufficiently high funding ratio).

For cushioned expected return based premiums, π_t should be such that future indexation is possible. Let EWI_t stand for the expected wage inflation at time t, according to the "Committee Parameters" (CP). Then π_t should be set such that

$$\frac{\sum_{g\in G_t^0} N_t^{(g)} \times (bp_t + \pi_t) W_t^{(g)}}{\sum_{g\in G_t^0} \sum_{\tau=T_t^{(g)}}^{\infty} {}_\tau p_t^{(g)} \times N_t^{(g)} \times D_{p,t}^{(\tau} \times a_t W_t^{(g)} (1 + EWI_t)^{\tau}} \geq 1,$$

or, equivalently,

$$bp_t + \pi_t \geq a_t \times \frac{\sum_{g\in G_t^0} \sum_{\tau=T_t^{(g)}}^{\infty} {}_\tau p_t^{(g)} \times N_t^{(g)} \times D_{p,t}^{(\tau} \times W_t^{(g)} (1 + EWI_t)^{\tau}}{\sum_{g\in G_t^0} N_t^{(g)} \times W_t^{(g)}}.$$

Thus, the expected return based premium is set to $c_t = bp_t + \pi_t$ satisfying this lower bound to ensure that enough assets are generated to be able to meet the corresponding liabilities when taking into account expected future indexation.

Our choices: Let T denote the starting period of our simulations. We use a constant term structure based premium with cushioning , i.e., we set $c_t = RFR_T \times bp_T$ for all $t \geq T$, with bp_T as given by equation (2.8) (for $t = T$), and using $d_{p,T}^{(\tau)} = \frac{1}{\widetilde{M}} \sum_{k=0}^{\widetilde{M}-1} d_{a,T-k}^{(\tau)} = \frac{1}{\widetilde{M}} \sum_{k=0}^{\widetilde{M}-1} R_{T-k}^{(\tau)}$, where $\widetilde{M}$ represents 10 years (with monthly data, $\widetilde{M} = 120$), and where $R_{T-k}^{(\tau)}$ follows from our model, see Section 2.7.3.

2.7.2.3 Immediate Recovery Plans

In this section we discuss recovery policies that have to be implemented immediately, when the Policy Funding Ratio turns out to be too low during five years in a row.

This immediate action should be taken as soon as the Policy Funding Ratio is below the minimal required funding ratio during $\overline{M}$ periods, where $\overline{M}$ represents 5 years, i.e., as soon as

$$PFR_{t-\tau} < MRFR_{t-\tau},$$

for $\tau = 0, 1, \cdots, \overline{M}$. This immediate action consists of implementing a recovery plan $IRec_t = (\rho_t^{ir})$, with $\rho_t^{ir} \in [0,1]$ the reduction factor to be applied to the pension entitlements $PE_t^{(g)}$. Given this recovery plan, the liabilities are calculated as

$$L_t^{ir} = \rho_t^{ir} L_t.$$

The recovery plan $IRec_t$ is an appropriate recovery plan if

$$\max\left\{FR_t^{ir}, PFR_t^{ir}\right\} \geq MRFR_t, \tag{2.9}$$

where $FR_t^{ir} = A_t/L_t^{ir}$ and where PFR_t^{ir} is calculated as the moving average using FR_t^{ir} instead of FR_t. In case of an appropriate recovery plan, we replace $PE_t^{(g)}$ by $\rho_{ir}^{r} PE_t^{(g)}$ and L_t by L_t^{ir}.

Our choices: We choose as immediate recovery plan $IRec_t = (\rho_t^{ir})$, where ρ_t^{ir} is set such that we have an equality in (2.9).

2.7.2.4 Ten Years Recovery Plans

In this section we discuss ten year recovery policies that have to be implemented, when the Policy Funding Ratio turns out to be lower than the Required Funding Ratio RFR_t.

Assume that the Policy Funding Ratio is below the required funding ratio, i.e., $PFR_t < RFR_t$. Let $Rec_t = (x_t^r, \pi_t^r, \rho_t^r)$ be part of the recovery plan applying to the first period $t+1$, with $x_t^r \in [0,1]$ determining the (lack of) indexation, $\pi_t^r \in [1, \infty)$ the (extra) raise in the pension contribution, and $\rho_t^r \in [0,1]$ the reduction factor to be applied to the pension entitlements.

We assume the following implementation of the recovery plan in period $t+1$:

- $W_{t+1}^{(g)} = W_t^{(g)}(1 + EWI)$,
- $I_{t+1} = 1 + x_t^r EWI$,
- $PE_{t+1}^{(g)} = PE_t^{(g)} \times I_t + a_t W_t^{(g)}$,
- $C_{t+1} = \sum_{g \in G_{t+1}^0} N_{t+1}^{(g)} \times (bp_t + \pi_t^r) W_{t+1}^{(g)}$,
- $P_{t+1} = \sum_{g \in G_{t+1}^1} N_{t+1}^{(g)} \times \rho_t^r PE_{t+1}^{(g)}$,
- $A_{t+1} = (1 + ER_t)(A_t - P_t) + C_t$,
- $L_{t+1} = P_{t+1} + \sum_{g \leq t+1} \sum_{\tau=\max\{1, T_{t+1}^{(g)}\}}^{\infty} {}_{\tau}p_{t+1}^{(g)} \times N_{t+1}^{(g)} \times D_{a,t,t+1}^{CP,(\tau)} \times \rho_t^r PE_{t+1}^{(g)}$,

with $D^{CP,(\tau)}_{a,t,t+1} = 1/(1 + d^{CP,(\tau)}_{a,t,t+1})^{\tau}$, where $d^{CP,(\tau)}_{a,t,t+1}$ denotes the predicted τ-periods ahead interest rate at time $t+1$, as it is predicted at time t according to the CP. The prediction $d^{CP,(\tau)}_{a,t,t+1}$ according to the CP is the time t forward rate between the periods $t+1$ and $t+1+\tau$.

This plan is an appropriate recovery plan under the following conditions:

- Its implementation guarantees a recovery of at least a fraction of 10% during the first period, i.e.,

$$PFR_{t+1} \geq PFR_t + 0.1 \times (RFR_t - PFR_t)\,. \tag{2.10}$$

- ρ^r_t is less than one, only if $x^r_t = 0$ and π^r_t is strictly larger than one, or, in case a pension contribution correction is excluded from the recovery plan (which means $\pi^r_t = 1$), ρ^r_t is less than one, only if $x^r_t = 0$.

Given such an appropriate recovery plan, we set $I_t = (1 + x^r_t WI_t)$, with WI_t the actual wage inflation during period t (averaged over the generations), and we replace π_t by π^r_t and $PE^{(g)}_{t+1}$ by $\rho^r_t PE^{(g)}_{t+1}$.

Our choices: We choose a ten years recovery plan where the pension contribution is excluded from the recovery plan (i.e., $\pi^r_t = 1$). We first try to set $x^r_t \in [0,1]$, with $\rho^r_t = 1$, to get an equality in (2.10). If even $x^r_t = 0$ does not suffice, we set $x^r_t = 0$ and choose $\rho^r_t \in [0,1]$ such that (2.10) is satisfied with an equality. We calculate the required forward rates using the zero-coupon yield curve ($R^{(T)}_t$) applying to period t. Thus, if $F^{(1,1+\tau)}_t$ denotes the time t forward rate between the periods $t+1$ and $t+1+\tau$, then we have

$$\left(1 + R^{(1)}_t\right)^1 \left(1 + F^{(1,1+\tau)}_t\right)^{\tau} = \left(1 + R^{(1+\tau)}_t\right)^{1+\tau},$$

or, equivalently,

$$F^{(1,1+\tau)}_t = \left(\frac{\left(1 + R^{(1+\tau)}_t\right)^{1+\tau}}{\left(1 + R^{(1)}_t\right)^1} \right)^{1/\tau} - 1.$$

2.7.2.5 Indexation Policies

In this section we discuss the indexation policies, i.e., policies determining the indexation factor I_t.

Let again EWI_t be the expected wage inflation according to the CP at time t (see previous sections). If there is no recovery plan, the indexation is set equal to $I_t = 1 + x_t^i WI_t$ (with WI_t the actual wage inflation), where $x_t^i \in [0,1]$ should satisfy

$$\frac{A_t - P_t}{\sum_{g \le t} \sum_{\tau=\max\{1,T_t^{(g)}\}}^{\infty} {}_\tau p_t^{(g)} \times N_t^{(g)} \times D_{i,t}^{(\tau)} \times (1 + x_t^i EWI)^\tau \times PE_t^{(g)}} \ge IFR_t, \quad (2.11)$$

with $d_{i,t}^{(\tau)} = ERS$, the Expected Returns on Stocks according to the CP. Thus, assuming that the indexation $1 + x_t^i EWI$ is applied to the present and future periods, the resulting funding ratio (after the payments of the pensions at the beginning of period t) should be at least IFR_t.

In case of a recovery plan $Rec_t = (x_t^r, \pi_t^r, \rho_t^r)$ (see previous section) the indexation will be set to $I_t = 1 + x_t WI_t$, with $x_t = \min\{x_t^i, x_t^r\}$. If $x_t^i < x_t^r$, the recovery plan Rec_t might have to be reconsidered.

Our choices: We first solve x_t^i, imposing an equality in (2.11) when WI_t is positive. If the solution is bigger than 1, we set $x_t^i = 1$. When $WI_t < 0$ or $PFR_t < 110\%$, we set $x_t^i = 0$. Without a recovery plan in period t, we set $I_t = 1 + x_t^i WI_t$. With a recovery plan $Rec_t = (x_t^r, \pi_t^r, \rho_t^r)$, we set $I_t = 1 + x_t WI_t$, with $x_t = \min\{x_t^i, x_t^r\}$. There is no need to reconsider the recovery plan.

2.7.2.6 Repair Policies

As a consequence of less than full indexation or as a consequence of the implementation of a recovery plan in the past we might have $PE_t^{(g)} < FIPE_t^{(g)}$ (where $FIPE_t^{(g)}$ are the pension entitlement under full indexation, see Notation and Set-Up). Repair policies are intended to decrease (or even close) the gaps between the actual and full indexation pension bases. We discuss these repair policies in this section.

Repair policies are only allowed to be implemented under a strict condition, namely $PFR_t \ge \max\{FIFR_t, RFR_t\}$, where $FIFR_t$ denotes the level of the funding ratio at which full indexation is possible, i.e.,

$$FIFR_t = A_t / \left(P_t + \sum_{g \le t} \sum_{\tau=\max\{1,T_t^{(g)}\}}^{\infty} {}_\tau p_t^{(g)} \times N_t^{(g)} \times D_{i,t}^{(\tau)} \times (1 + EWI)^\tau PE_t^{(g)} \right).$$

If the condition $PFR_t \ge \max\{FIFR_t, RFR_t\}$ is satisfied, 20%[19] of the excess funds may be used to repair (part of) the gaps $PE_t^{(g)} - FIPE_t^{(g)} < 0$.

[19]In the original proposal, it was 10%. After the parliament discussion, some amendments were made, among which is the recovery fraction.

Let FRA_t denote the fraction of available funds for repair, i.e.,

$$FRA_t = 0.2 \times \max\{0, PFR_t - \max\{FIFR_t, RFR_t\}\}.$$

As immediate repair plan we consider $Rep_t = (\alpha_t^r)$, with $\alpha_t^r \in [0,1]$, with the aim to replace $PE_t^{(g)}$ by $\widetilde{PE}_t^{(g)}$, given by

$$\widetilde{PE}_t^{(g)} = PE_t^{(g)} + \alpha_t^r(FIPE_t^{(g)} - PE_t^{(g)}).$$

The repair plan Rep_t is an appropriate repair plan if $A_t/\widetilde{L}_t \geq (1 - FRA_t) \times PFR_t$ or

$$\widetilde{L}_t \leq \frac{1}{1 - FRA_t} \times \frac{A_t}{PFR_t}, \tag{2.12}$$

with

$$\widetilde{L}_t = \sum_{g \in G_t^1} N_t^{(g)} \times \widetilde{PE}_t^{(g)} + \sum_{g \leq t} \sum_{\tau = \max\{1, T_t^{(g)}\}}^{\infty} {}_\tau p_t^{(g)} \times N_t^{(g)} \times D_{a,t}^{(\tau)} \times \widetilde{PE}_t^{(g)}.$$

In this case we replace $PE_t^{(g)}$ by $\widetilde{PE}_t^{(g)}$ and L_t by $\widetilde{L}_t$.

Our choices: We choose our immediate repair plan $Rep_t = (\alpha_t^r)$ to minimize $A_t/\widetilde{L}_t - (1 - FRA_t) \times PFR_t$ with $\alpha_t^r \in [0,1]$.

2.7.2.7 Premium Reduction Policies

Under favorable circumstances, premium reductions, resulting in a premium below the minimum premium level bp_t, are possible. In this section we discuss such premium reduction policies.

A premium reduction below the minimum level bp_t is possible if

- $PFR_t \geq RIFR_t$, with $RIFR_t$ the lower bound for premium reduction, set by the pension fund, with $RIFR_t \geq RFR_t$,
- $I_{t-\tau} = FI_{t-\tau}$, $\tau = 1, \cdots, 10$,
- $PE_t^{(g)} = FIPE_t^{(g)}$, for all generations $g \leq t$.

Under these conditions, let $Red_t = (\pi_t^{pr})$, with $\pi_t^{pr} < c_t - bp_t$, be an immediate premium reduction plan. It is an appropriate premium reduction plan if, in case of a term structure based premium, we have

$$\frac{\sum_{g \in G_t^0} N_t^{(g)} \times (bp_t + \pi_t^{pr}) W_t^{(g)}}{\sum_{g \in G_t^0} \sum_{\tau = T_t^{(g)}}^{\infty} {}_\tau p_t^{(g)} \times N_t^{(g)} \times D_{p,t}^{(\tau)} \times a_t W_t^{(g)}} \geq RFR_t. \tag{2.13}$$

with $MRFR_t = \max\{RIFR_t, RFR_t\}$, or if, in case of an expected return based premium,

$$\frac{\sum_{g \in G_t^0} N_t^{(g)} \times (bp_t + \pi_t^{pr}) W_t^{(g)}}{\sum_{g \in G_t^0} \sum_{\tau = T_t^{(g)}}^{\infty} {}_\tau p_t^{(g)} \times N_t^{(g)} \times D_{p,t}^{(\tau} \times \widetilde{PW}_{t,t+\tau}^{(g)}} \geq 1. \tag{2.14}$$

(see Premium Policies for details). We then set $\hat{c}_t = bp_t + \pi_t^{pr} < c_t$.

Our choices: We set $RIFR_t = RFR_t$, and we choose the immediate premium reduction plan $Red_t = (\pi_t^{pr})$ such that we have an equality in (2.13) (corresponding to a term structure based premium).

2.7.3 The Economic Setting

In this section we provide additional information concerning the economic setting used in this chapter. First, Subsection 2.7.3.1 contains information on the construction of some of the variables used. Our estimation and calibration procedure consists of two steps, a first step to estimate the VAR-model and a second step to calibrate the price of risk. In Subsection 2.7.3.2 we provide additional information on the first step. In Subsection 2.7.3.3 we then describe the modeling of the term structure of interest rates. Subsection 2.7.3.4 presents the outcomes of the second step of our estimation and calibration procedure.

2.7.3.1 Some Variable Definitions

Inflation is calculated as

$$cpi_t = 2 \times \ln \frac{CPI_t}{CPI_{t-6}} \tag{2.15}$$

where CPI_t is the consumer price index at time t. Wage inflation is calculated in the same way from the CAO wage index. The stock return premium is derived from the MSCI world total return stock index which is in U.S. dollars. We use the USD to EUR (WMR&DS) exchange rate to express the return in euros. We first compute the annualized 6-month stock return in local currency (USD) from the total return index using the formula below:

$$r_{t,s,l} = \ln\left(\frac{\text{Index}_t}{\text{Index}_{t-6}}\right) \times 2. \tag{2.16}$$

Then the return in euros can be derived from

$$r_{t,s} = (1 + r_{t,s,l})(1 + r_{t,x}) - 1, \tag{2.17}$$

where $r_{t,x}$ is the return from the local currency appreciation (depreciation).

2.7.3.2 First Step Estimation

In the first step, we use maximum likelihood method to estimate the coefficients of the VAR model. Since the error terms in the VAR model are *i.i.d.* jointly normally distributed, the likelihood function is given by

$$\ell(\mu, \Gamma, \Sigma | x_0, \cdots, x_t) = \prod_{t=1}^{T} f(x_{t-1}, x_t | \mu, \Gamma, \Sigma) \tag{2.18}$$

where

$$\begin{aligned} f(x_{t-1}, x_t | \mu, \Gamma, \Sigma) = & \frac{1}{\sqrt{(2\pi)^N |\Sigma\Sigma'|}} \\ & \exp\left(-\frac{1}{2}(x_t - \mu - \Gamma(x_{t-1} - \mu))'(\Sigma\Sigma')^{-1}(x_t - \mu - \Gamma(x_{t-1} - \mu))\right) \end{aligned} \tag{2.19}$$

When choosing the number of lags of the VAR model, we used the information criteria as shown in Table 2.7. The Akaike Information Criterion (AIC) suggests higher lags while the Bayesian Information Criterion (BIC) suggests lag 1. Previous studies show that the AIC might be inconsistent whereas the BIC is generally statistically consistent, see, for example, van Erven et al. (2012). Therefore, we choose the order of lags based on the BIC.

	VAR(1)	VAR(2)	VAR(3)	VAR(4)
AIC	-9240.63	-9245.16	-9263.35	-9269.81
BIC	-9077.23	-8990.97	-8918.39	-8834.06

Table 2.7: This table presents the values of two Information Criteria of the VAR-model presented in section 2.3 with different lags. AIC is the Akaike Information Criterion and BIC is Schwartz's Bayesian Information Criterion.

Table 2.8 presents the empirical and model-based means and correlations between the five state variables, where the model-based correlations are calculated using the VAR-model with one lag. The table also contains the p-values for testing the null hypothesis that the corresponding correlation is equal to zero. Most correlations are statistically significantly different from zero, using the conventional significance levels.

2.7.3.3 The Term Structure of Interest Rates

We assume that the prices are set such that arbitrage opportunities are excluded. This implies the existence of a pricing kernel M_t, for all t, which we postulate to be

	Correlation Matrix Implied by Data					Sample Mean
$y^{(1)}$	1.000	0.339	-0.112	-0.700	0.485	0.035
cpi	0.339	1.000	-0.078	-0.298	0.442	0.022
$r_s - y^{(1)}$	-0.112	-0.078	1.000	0.155	-0.205	0.029
$y^{(20)} - y^{(1)}$	-0.700	-0.298	0.155	1.000	-0.471	0.014
$wage$	0.485	0.442	-0.205	-0.471	1.000	0.023
	p-values of the correlations					
		0	0.0582	0	0	
	0		0.1865	0	0	
	0.0582	0.1865		0.0086	0.0005	
	0	0	0.0086		0	
	0	0	0.0005	0		
	Correlation Matrix Implied by Model					Model Mean
$y^{(1)}$	1.000	0.253	-0.088	-0.195	0.297	0.032
cpi	0.253	1.000	0.028	-0.025	0.243	0.022
$r_s - y^{(1)}$	-0.088	0.028	1.000	0.041	-0.041	0.043
$y^{(20)} - y^{(1)}$	-0.195	-0.025	0.041	1.000	0.037	0.016
$wage$	0.297	0.243	-0.041	0.037	1.000	0.022

Table 2.8: Means and Correlation Matrices of the five state variables.

given by

$$M_{t+1} = \exp\left(-(\delta_0 + \delta_1' x_t + \frac{1}{2}\lambda_t'\lambda_t + \lambda_t'\varepsilon_{t+1})\right), \tag{2.20}$$

where δ_0 is a constant and δ_1 is an n-dimensional vector of constants, ε_{t+1} is the innovation defined in equation (2.1), and λ_t is the price of risk, which is postulated to be affine in the state variables x_t, i.e.,

$$\lambda_t = \Lambda_0 + \Lambda_1 x_t. \tag{2.21}$$

where Λ_0 is a n-dimensional vector of unknown parameters, and Λ_1 is an $n \times n$-dimensional matrix of unknown parameters, that accounts for part of the risk premium, sensitive to changes in the state vector x_t.

The nominal term structure describes the nominal interest rates as a function of time to maturity. It can be derived from the yields of zero-coupon bonds. The yield to maturity of a zero-coupon bond is defined as $R_t^{(T)}$ and the relation between the zero-coupon bond price and the corresponding yield to maturity is given by

$$P_t^{(T)} = \exp(-TR_t^{(T)}). \tag{2.22}$$

For $T = 1$ we get

$$R_t^{(1)} = -\log(P_t^{(1)}) = \mathbb{E}_t\left(M_{t+1} \times 1\right) = \delta_0 + \delta_1' x_t.$$

Thus, $\delta_0 + \delta_1 x_t$ is the short rate $R_t^{(1)}$. The short rate is the first state variable in the VAR model. To make the model self-consistent, we therefore set $\delta_0 = 0$ and $\delta_1' = (1, 0, 0, 0, 0)$.

A T-year zero coupon bond at time t will become a $T-1$ year zero coupon bond one year later, with payoff after one year given by P_{t+1}^{T-1}. Therefore, the price of this zero coupon bond at time t satisfies,

$$P_t^{(T)} = \mathbb{E}_t\left(M_{t+1} P_{t+1}^{(T-1)}\right) \tag{2.23}$$

By postulating

$$\log(P_t^{(T)}) = -A(T) - B(T)' x_t, \tag{2.24}$$

we can solve $A(T)$ and $B(T)$ recursively, which results in the following equations:

$$\begin{aligned} A(T) &= A(T-1) + B(T-1)'\alpha - \tfrac{1}{2} B(T-1)'\Sigma\Sigma' B(T-1) - B(T-1)'\Sigma\Lambda_0 \\ B(T) &= (\Gamma - \Sigma\Lambda_1)' B(T-1) + \delta_1 \end{aligned} \tag{2.25}$$

with as starting values $A_0 = 0$, $B_0 = 0_n$, following from $\log P_t^{(0)} = \log(1) = 0$. We then also have $R_t^{(T)} = a(T) + b(T)' x_t$, with $a(T) = -A(T)/T$ and $b(T) = -B(T)/T$.

2.7.3.4 Second Step Calibration

In the second step, we calibrate the price of risk λ_t to the observed term structure by minimizing the squared difference of the estimated model-based yields and the corresponding observed yield.

As follows from (3.16) the pricing kernel M_{t+1} is lognormally distributed. The expectation of the corresponding normal distribution is given by $-(\delta_0 + \delta_1 x_t + \frac{1}{2}\lambda_t'\lambda_t)$ and its variance is $\lambda_t'\lambda_t$. So, we can express the variance of the stochastic discount factor as:

$$\begin{aligned} \mathrm{var}(M_{t+1}) &= \left(e^{\lambda_t'\lambda_t} - 1\right) e^{-2(\delta_0 + \delta_1 x_t + \frac{1}{2}\lambda_t'\lambda_t) + \lambda_t'\lambda_t} \\ &= \left(e^{\lambda_t'\lambda_t} - 1\right) e^{-2(\delta_0 + \delta_1 x_t)}. \end{aligned} \tag{2.26}$$

The variance of the pricing kernel strongly depends on the magnitude of $\lambda_t'\lambda_t$. If $\lambda_t'\lambda_t$ is very large, this variance will explode, potentially complicating a Monte Carlo simulation analysis. To avoid this from happening, we include the variance of the pricing kernel as a penalty in the objective function. The objective function that we minimize then becomes

$$\omega_1 \sum_t \sum_T (\hat{R}_t^{(T)} - R_t^{(T)})^2 + \omega_2 \text{var}(M_{t+1}), \tag{2.27}$$

where $\hat{R}_t^{(T)}$ is the estimated interest rate for maturity T at time t and $R_t^{(T)}$ is the observed interest rate for maturity T at time t. The weights are given as follows: $\omega_1 = 99.99\%$, $\omega_2 = 0.01\%$, and x_t is substituted by its model implied average.

We cannot simply choose any combination of Λ_0 and Λ_1 that minimizes the objective function as described in equation (2.27). To make the model self-consistent and stable, we impose several constraints.

- First, there is a model implied 10-year interest rate but at the same time, the 10-year interest rate spread also enters into our VAR model. Since our short rate is 6-month federal security rate, one period is 6-month, so the 10 year rate is actual the 20-periods interest rate. We have $R_t^{(20)} = a(20) + b(20)'x_t$ and the 10-year interest rate implied by the VAR model is $R_t^{(10)} = (e_i + e_j)'x_t$, where e_i is the unit vector with the ith element the short rate and e_j is another unit vector with the jth element the 10-year interest rate spread. By setting the right hand sides of the above two equations equal to each other, we obtain $a(20) = 0$ and $b(20) = e_i + e_j$.

- Second, the stock return premium appears in the VAR model and is implied by the risk premium in the pricing kernel. Let $R_{s,t+1}$ stand for the net return on the stock index, and define $r_{s,t+1} \equiv \log(1 + R_{s,t+1})$. Then we should have

  $$1 = E_t \left[M_{t+1}(1 + R_{s,t+1})\right]$$

  Taking logarithms on both sides, we have,

  $$0 = \log(E_t \left[M_{t+1}(1 + R_{s,t+1})\right]) = E_t(\log(M_{t+1}) + r_{s,t+1}) + \frac{1}{2} Var_t(\log(M_{t+1}) + r_{s,t+1}).$$

  Since $\log(M_{t+1}) = -y_t - \frac{1}{2}\lambda_t'\lambda_t - \lambda_t'\epsilon_{t+1}$, we find

  $$\begin{aligned} 0 &= E_t(-y_t - \frac{1}{2}\lambda_t'\lambda_t - \lambda_t'\epsilon_{t+1}) + E_t(r_{s,t+1}) + \frac{1}{2} Var_t(-y_t - \frac{1}{2}\lambda_t'\lambda_t - \lambda_t'\epsilon_{t+1} + r_{s,t+1}) \\ &= -y_t - \frac{1}{2}\lambda_t'\lambda_t + y_t + e_s'(\alpha + \Gamma x_t) + \frac{1}{2}\lambda_t'\lambda_t + \frac{1}{2} e_s'\Sigma\Sigma' e_s - e_s'\Sigma\lambda_t \\ &= e_s'(\alpha + \Gamma x_t) + \frac{1}{2} e_s'\Sigma\Sigma' e_s - e_s'\Sigma(\Lambda_0 + \Lambda_1 x_t) \end{aligned}$$

Thus, the constraint on the stock return premium is

$$
\begin{aligned}
e_s'\Sigma\Lambda_0 &= e_s'\alpha + \frac{1}{2}e_s'\Sigma\Sigma' e_s \\
e_s'\Sigma\Lambda_1 &= e_s'\Gamma
\end{aligned}
$$

- Third, as shown in equation (3.20), the process of $B(T)$ is a first order autoregressive series with coefficient matrix $(\Gamma - \Sigma\Lambda_1)'$. To ensure the stability of the model, we add as constraint that all the eigen-values of $\Gamma - \Sigma\Lambda_1$ are within the unit circle.

- We set the ultimate yield $a(\infty)$ in our model equal to 4.2%. We have:

$$
a(\infty) = \lim_{T\to\infty} \frac{A(T)}{T} = B(\infty)'\alpha - 0.5B(\infty)'\Sigma\Sigma' B(\infty) - B(\infty)'\Sigma\Lambda_0
$$

where $B(\infty)$ satisfies $B(\infty) = (\Gamma - \Sigma\Lambda_1)'B(\infty)$. So, the last constraint is

$$
\begin{aligned}
&((I - (\Gamma - \Sigma\Lambda_1)')^{-1}\delta_1)'(\alpha - \Sigma\Lambda_0) - 0.5((I - (\Gamma - \Sigma\Lambda_1)')^{-1}\delta_1)'\Sigma\Sigma' \\
&((I - (\Gamma - \Sigma\Lambda_1)')^{-1}\delta_1) \qquad (2.28)\\
&= 0.042.
\end{aligned}
$$

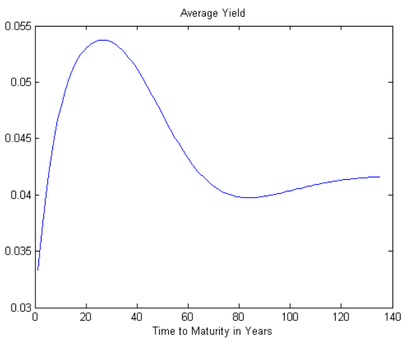
The second step calibration results are shown in Table 2.9.

	Λ_0	Λ_1				
$y^{(1)}$	1.4427	-16.6623	-3.8282	0.3328	-69.1103	-8.1960
cpi	8.5830	-91.6736	-62.3017	-49.7687	-55.9294	-19.5505
$r_s - y^{(1)}$	-0.0557	6.0829	-7.1205	9.0118	2.0227	-4.7016
$y^{(20)} - y^{(1)}$	-1.3127	19.0576	-6.6427	0.5693	58.2557	3.5234
$wage$	-4.5112	8.7138	44.5454	59.7123	2.5231	28.7268

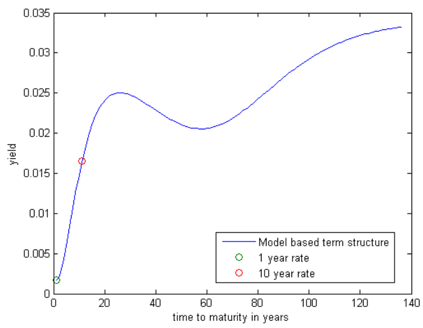
Table 2.9: This Table presents the second step calibration results. Column Λ_0 shows the calibrated constant part of the risk premium and column Λ_1 shows the time varying part.

Figure 2.12 shows both the average term structures as implied by the model for time to maturity up to 135 years and the current term structure. The Figure also shows a sample of simulated term structures. The panel with the current term structure also shows the corresponding 6-month yield and 10-year yields.

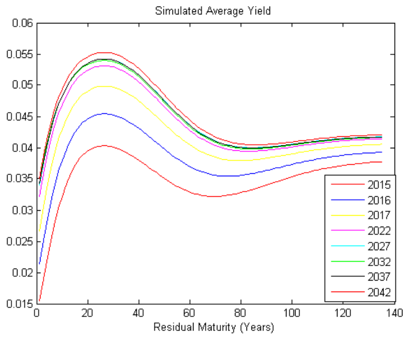
To further investigate the model fit, we compare the model-based mean and volatility of the yield in our model to the historical ones, see Figure 2.13. We simulate the



(a) Average term structure.

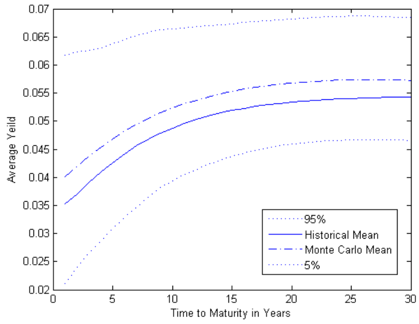


(b) Current term structure.

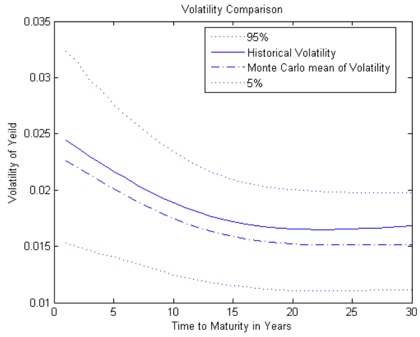


(c) Sample of simulated term structures.

Figure 2.12: Panel (a) shows the average model-based term structure. Panel (b) shows the model-based current term structure and the corresponding sample-based 0.5 year and 10 year interest rates. Panel (c) presents some simulated term structures. The lines from the bottom to the top in Panel (c) represent term structure of the year 2015, 2016, 2017, 2022, 2027, 2032, 2037, and 2042, respectively.



(a) Comparison of model-based and sample average yields.



(b) Comparison of model-based and sample yield volatilities.

Figure 2.13: **Term Structure Means and Volatilities.** Panel (a) and panel (b) compare the model-based and sample-based results.

stochastic term structure for 1000 paths for a period that is equal to the time horizon of the observed term structure. We then plot the average yield and the 5% and 95% quantiles of the simulated yields and compare these to the historical average yield. We do a similar comparison for the volatility, plotting the average volatility, the 5% and the 95% quantile of the volatility of the yield and the volatility of the observed yield in the same picture. As shown in Figure 2.13, the historical mean and volatility are between the 5% and 95% quantiles.

Chapter 3

Model Risk in the Pricing of Reverse Mortgage Products

3.1 Introduction

When people are approaching their retirement age, their human capital decreases, while unexpected expenditures on health care may occur. Moreover, the main source of post-retirement income, the pension payment, is threatened. This occurs because the pension system is under stress due to the financial crisis and its aftermath, the aging population, and retirement of the baby boom generation. With a less stable income from the pension system and longer life expectancy, individuals might face considerable financial problems after retirement. At the same time, a large proportion of their accumulated wealth is typically invested in housing equities, which, if liquidated, can generate substantial post-retirement income. A reverse mortgage is one of the products available on the market that allows the elderly to use home equity to finance retirement income, while staying in their home (until death or permanently moving out of the home due to other reasons).

There has been a growing literature studying three aspects of reverse mortgage products. The first aspect is the market volume of the product. Earlier empirical studies found that the demand for reverse mortgages was very small. According to this earlier research (Venti, Wise, 1991), an annuity reverse mortgage cannot substantially increase the income of average elderly and very few families chose to increase their post-retirement income by equitizing their house. However, since the New Millennium, the reverse mortgage market began to expand. In the US, \$30.21 billion of reverse mortgage loans were made in 2009, which was a record. In Hong Kong, in a survey conducted among middle-aged adults in 2000, approximately 11% of the homeowners indicated that they would definitely or probably apply for a reverse mortgage if it were available (Chou et al. 2006). According to Shan (2011), the main reason that led to the market expansion is the increasing house price, which can account for one third of the growth between 2003 and 2007.

The second aspect the literature is trying to explain is why the demand for reverse mortgages is below what one might expect. Bequest motives play a substantial role in the decision of elderly home-owners whether to enter into a reverse mortgage contract (Davidoff, 2010, Michelangeli, 2008). Empirical studies found that childless elderly are more likely to buy reverse mortgages (Chou *et al.*, 2006). Adverse selection and moral hazard are other reasons that may reduce the demand. People who buy annuities tend to have a longer life expectancy (McCarthy and Mitchell, 2010, Finkelstein and Poterba, 2002). Since some reverse mortgage designs have similar characteristics as annuities, the adverse selection problem may also exist in the reverse mortgage market. The moral hazard arises when a reverse mortgage buyer reduces the expenditure on maintaining the condition of the house (Shiller and Weiss, 2000, Miceli and Sirmans, 1994). The complexity of the product also hinders potential buyers from entering the market (Davidoff *et al.* 2015).

The third aspect the literature is focusing on is the pricing and risk analysis of the product. Longevity risks, house price risks and the price of the embedded "No-Negative-Equity Guarantee" (*NNEG*) are all discussed extensively (Wang, *et al.*, 2008, Li, *et al.*, 2010, Yang, *et al.*, 2011, Chen, *et al.*, 2010, Lee, 2012, Shao, *et al.*, 2015, Ji *et al.*, 2012.). To evaluate different reverse mortgage designs one needs to value the various cash flows involved. This requires the use of quantitative models, including the quantification of interest rates, house prices, mortality, and so on. Typically, in order to get a manageable model, one has to make use of simplifying assumptions. However, the use of a simple model may come at the cost of model risk, i.e., one has to deal with a model that is potentially misspecified (in addition to model parameter values that might be imprecise due to sampling error). Although different models which are potentially misspecified are developed to quantify the risks and price the *NNEG*, model risk is typically not investigated.

We investigate the impact of model risk on the price of the *NNEG*. We consider two types of models to value the *NNEG* for various reverse mortgage designs. In the first model, the house price follows a Geometric Brownian Motion (GBM) while in the second model, the house price is modeled using a VAR model (together with other economic variables). Both models are popular in previous studies on reverse mortgages. For instance, Szymanoski (1994), Wang *et al.* (2008), Ji *et al.* (2012)

assume that a GBM drives the house price, and Shao *et al.* (2015), Sherris and Sun (2010), Alai *et al.* (2014), Cho *et al.* (2013) use a Vector Autoregressive Model (VAR) to model the interrelation between house price and other economic variables. While previous studies have used the two models, the issue of model risk has, to the best of our knowledge, not been investigated.

In this paper, we first investigate the sensitivity of the price of the *NNEG* to changes in the (calibrated or estimated) model parameters. In both models we interpret the house as a dividend paying asset, where the dividend is parameterized by the dividend yield. As an asset the house might have a nonzero price of idiosyncratic risk. In the models we consider, the dividend yield is negatively related to the house price growth rate, but also depends on the price of idiosyncratic risk of the house. Our analysis shows that in both models, the price of the *NNEG* is highly sensitive to the dividend yield. This high sensitivity is a concern because the dividend yield cannot be determined using only house price data if the house has a nonzero price of idiosyncratic risk. But also with a zero price of idiosyncratic risk (a possibility that we consider in the VAR model) the dividend yield is difficult to estimate or calibrate accurately. Due to the recent crisis on the housing market, estimates can be highly sensitive to the period that is chosen to estimate or calibrate the model parameters. Therefore, as an alternative, we use data on prices of regular mortgages to calibrate the dividend yield. Using these calibrated ranges of the dividend yield, we then determine the model implied price ranges of the *NNEG* for different reverse mortgage products. We find quite substantial price ranges, indicating that there is substantial model risk.

The organization of the remainder of the paper is as follows. In Section 3.2, we present three basic reverse mortgage schemes and describe the cash flow pattern for each scheme. In Section 3.3, we determine the market consistent reverse mortgage rate and quantify the value of the *NNEG*. We apply the GBM model in Section 3.4 and VAR model in Section 3.5 to price the *NNEG* and analyze its sensitivity to parameter risk. Section 3.6 studies the model risk. We conclude in Section 3.7.

3.2 Reverse Mortgage Schemes

In this section, we present the reverse mortgage contract designs that we investigate in this paper. A summary of the notation used in the paper can be found in Table 3.10 in the Appendix.

A reverse mortgage is a loan that allows homeowners to convert (part of) the value of their house value into cash. Instead of a fixed end date, as in case of a traditional mortgage, the borrower pays back the loan when (s)he dies, or when the home is sold. This time is denoted as date T. The initial loan amount is typically expressed as a fraction φ of the house value, i.e., the initial loan amount is

$$L_0 = \varphi H_0, \tag{3.1}$$

where H_0 is the value of the house at the beginning of the contract. The fraction φ is referred to as the *loan-to-value ratio*. This is a contract parameter, whose maximum value is set by the lender, typically depending on characteristics of the house and on the characteristics of the owners, such as, for example, their ages. Instead of receiving a lump sum amount, the loan can also take the form of a whole life annuity of value $L_0 = \varphi \cdot H_0$. On date T, the house is sold and the net revenues of sales are used to pay back the loan. To protect the buyer of the reverse mortgage from negative equity, the contract includes a No-Negative-Equity-Guarantee, *NNEG*. Specifically, the repayment of debt on date T is capped at the net revenue from selling the house. This implies that the outstanding debt is not fully repaid in case the net revenues from the house are lower than the outstanding debt; the lender offers the buyer a guarantee NN_T which is defined as follows:

$$NN_T = \begin{cases} L_T - (1-\delta) \cdot H_T, & \text{if } (1-\delta) \cdot H_T < L_T, \\ 0, & \text{if otherwise,} \end{cases} \tag{3.2}$$

where L_T is the loan balance on date T, H_T is the house price on date T, and δ is the proportional transaction cost in case of a (forced) sale. On date $t = 0$, the lender charges a premium π_{NN} to cover for the guarantee.

To summarize, the main characteristics of the reverse mortgage are as follows:

- The borrower either receives a lump-sum amount of $L_0 = \varphi H_0$ on date zero, or receives a flat amount per period until the contract terminates.
- On date 0, the borrower pays a premium π_{NN} for the *NNEG* to the lender.
- When the contract terminates on date T, the lender receives the minimum of the loan balance on date T, which is denoted as L_T, and the net revenues from selling the house, i.e., the lender receives $\min\{(1-\delta) \cdot H_T, L_T\} = L_T - NN_T$.

It remains to specify how the loan balance accrues over time. We assume that contract termination occurs at the end of a period, i.e., $T \in \mathcal{T} = \{1, 2, \ldots, T_{\max}\}$, and that any intermediate payments occur only on dates $t \in \mathcal{T}$. We consider reverse mortgage schemes in which the lender charges a deterministic interest rate of r per period. Whether the borrower pays interest before date T depends on the type of reverse mortgage, as discussed below.

Lump sum contract—A lump-sum reverse mortgage product pays a lump-sum amount at contract initiation. It is the most common type of reverse mortgage in most of the markets. There are no intermediate interest payments and no principal repayment before contract termination. Thus $L_0 = \varphi H_0$, and the loan balance on date T, denoted by L_T, equals:

$$L_T = L_0(1 + r)^T. \tag{3.3}$$

Hence, the cash flow stream of the reverse mortgage is as follows:

- $t = 0$: the borrower receives $L_0 - \pi_{NN}$ from the lender, where π_{NN} is the premium for the guarantee.
- $t = T$: the lender receives $L_T - NN_T$ from the borrower.

Interest only contract—The contract is the same as the lump-sum contract, except that now each year the borrower pays interest on the outstanding debt. So, the initial loan amount again equals $L_0 = \varphi H_0$, but now, due to payment of interest, the loan balance stays constant. Thus, the loan balance on date T equals:

$$L_T = L_0. \tag{3.4}$$

The cash flow stream of the reverse mortgage is as follows:

- $t = 0$: borrower receives $L_0 - \pi_{NN}$.
- $t \in \{1, \ldots, T\}$: the borrower pays interest rL_0.
- $t = T$: the lender receives $L_T - NN_T$ from the borrower.

Tenure contract—The tenure reverse mortgage product pays a fixed amount C at the end of each period until the termination of the contract. This means that the loan balance at time T is given by

$$L_T = C \sum_{s=1}^{T} (1 + r)^s. \tag{3.5}$$

The cash flow stream is as follows:

- $t = 0$: the borrower pays the premium π_{NN}.
- $t \in \{0, \ldots, T-1\}$: the borrower receives C.
- $t = T$: the lender receives $L_T - NN_T$ from the borrower.

The fixed payment C will be set such that the market value of the payments equals φH_0. This will be determined in the next section.

Table 3.1 summarizes the net cash flows from the point of view of the lender in each of the three cases.

	$t=0$	$t=1$	$\cdots$	$t=T-1$	$t=T$
Lump-sum	$\pi_{NN} - L_0$	0	$\cdots$	0	$L_T - NN_T$
Interest only	$\pi_{NN} - L_0$	rL_0	$\cdots$	rL_0	$rL_0 + L_0 - NN_T$
Tenure	$\pi_{NN} - C$	$-C$	$\cdots$	$-C$	$L_T - NN_T$

Table 3.1: This table presents the net cash flows from the point of view of the lender in the three reverse mortgage schemes. In case of the lump sum and interest only contract we have $L_0 = \varphi H_0$. In case of the lump sum contract, we have $L_T = L_0(1+r)^T$, in case of the interest only contract, we have $L_T = L_0$, and in case of the tenure contract we have $L_T = C\sum_{s=1}^{T}(1+r)^s$.

3.3 Pricing Reverse Mortgage Products

To determine the price of the reverse mortgage, we split it into two parts. We first determine the market-consistent interest rate r for the "regular" loan without the *NNEG*. We then calculate the *NNEG* as the present value of the loss of the lender at contract termination. We assume that the conditions under which this loan is offered are market-consistent, i.e., arbitrage opportunities are excluded. This means the existence of a Stochastic Discount Factor (SDF) $M_t > 0$ such that a (random) payoff X_t at time t has price $E(X_t M_t)$ at time 0. In addition, we assume that mortality risk is independent of the other sources of risk (house price risk and financial risk), i.e., T is independent of (H_t, M_t).[1] Thus, we have

[1]The assumption that T is independent of (H_t, M_t) does not exclude the possibility that there is dependence between mortality and other sources of risk under the actual probability distribution: the *actual* SDF $\widetilde{M}_t$ might satisfy $\widetilde{M}_t = M_t \Lambda_t$, where Λ_t represents the change of measure going from the actual probability measure to the probability measure used in pricing (and which might be converted into the risk neutral probability distribution). In the former there might be dependence between mortality and the other risk sources. Only in the latter we assume independence between T and (H_t, M_t).

- $P_0^{(t)} = \mathbb{E}(M_t)$,

with $P_0^{(t)}$ the time 0 price of a zero coupon bond that pays off 1 at maturity, with time-to-maturity t, and we have

- $\mathbb{E}(M_T) = \sum_{t=1}^{T_{\max}} \mathbb{E}(M_t|T=t)\mathbb{P}(T=t) = \sum_{t=1}^{T_{\max}} P_0^{(t)}\mathbb{P}(T=t)$,

where T_{max} denotes the maximum value of T and using $\mathbb{E}(M_t|T=t) = \mathbb{E}(M_t)$.

3.3.1 Termination Date

In this section, we model the probability distribution of the termination date T. We consider the case where the contract terminates upon the decease of the last surviving household member. If the borrower is a single person, $T = T_x$, where T_x is the remaining lifetime of the borrower at time $t = 0$. If the borrower is a couple consisting of a male aged x and a female aged y, then $T = \max\{T_x, T_y\}$, where T_x and T_y are the remaining lifetimes of the spouses at time $t = 0$.

To model the probability distribution of T, we let ${}_sp_{z,t}^{(g)}$ denote the probability that a z-year-old in year t with gender $g \in \{m, f\}$ survives at least s more years, and let $q_{z,t}^{(g)}$ be the probability that a z-year-old in year t with gender g dies within a year. We assume that death always occurs at the end of a year. Moreover, in case of a couple, we assume that T_x and T_y are independent. Then, the probability that the contract terminates at the end of year t, $\mathbb{P}(T=t)$, is given by

$$\mathbb{P}(T=t) = {}_{t-1}p_{x,0}^{(g)} \cdot q_{x+t-1,t-1}^{(g)}$$

in case of a single insured of gender g and aged x at time $t = 0$, and is given by

$$\begin{aligned} \mathbb{P}(T=t) = &\left({}_{t-1}p_{y,0}^{(f)} \cdot q_{y+t-1,t-1}^{(f)}\right) \cdot \left(1 - {}_{t-1}p_{x,0}^{(m)}\right) \\ &+ \left(1 - {}_{t-1}p_{y,0}^{(f)}\right) \cdot \left({}_{t-1}p_{x,0}^{(m)} \cdot q_{x+t-1,t-1}^{(m)}\right) \\ &+ \left({}_{t-1}p_{y,0}^{(f)} \cdot q_{y+t-1,t-1}^{(f)}\right) \cdot \left({}_{t-1}p_{x,0}^{(m)} \cdot q_{x+t-1,t-1}^{(m)}\right), \end{aligned} \tag{3.6}$$

for a couple with a male aged x and a female aged y at time $t = 0$.

3.3.2 Pricing the Loan without the Guarantee

In this section, we determine the market-consistent fixed interest rate for the mortgage without the *NNEG*. For each of the three types of reverse mortgage, the market-consistent interest rate r is determined such that the market value of the net cash flow stream to the lender (as displayed in Table 1) is zero, given $\pi_{NN} = NN_T = 0$.

Lump sum contract—In absence of the *NNEG*, the lender pays L_0 to the borrower on date zero, and receives $L_T = (1+r)^T \cdot L_0$ from the borrower upon contract termination. Therefore, the market-consistent interest rate r solves:

$$L_0 = \mathbb{E}(L_T M_T) = L_0(1+r)^T \cdot \mathbb{E}(M_T),$$

or, equivalently (after canceling L_0 from both sides),

$$1 = \sum_{t=1}^{T_{\max}} (1+r)^t \cdot P_0^{(t)} \cdot \mathbb{P}(T=t). \tag{3.7}$$

Thus, the required interest rate r depends on the term structure of interest rate at contract initiation as well as on the probability distribution of the termination time T.

Interest only contract—The lender offers a loan of L_0 on date zero, receives interest payments rL_0 in any year prior to termination, and receives L_0 upon contract termination. The market-consistent interest rate r in this case satisfies (after canceling L_0 from both sides):

$$1 = \sum_{t=1}^{T_{\max}} \left[r \sum_{s=1}^{t} P_0^{(s)} + P_0^{(t)} \right] \cdot \mathbb{P}(T=t). \tag{3.8}$$

Tenure contract—The lender pays the constant amount C to the borrower at times $t = 0, \ldots, T-1$, and receives $L_T = C\left(\sum_{s=1}^{T}(1+r)^s\right)$ at time T. We assume that C is set such that the market value of the payments at time $t=0$ equals φH_0, i.e.,

$$\varphi H_0 = C \times \left(\sum_{t=0}^{T_{\max}-1} \mathbb{P}(T>t) \cdot P_0^{(t)} \right). \tag{3.9}$$

The market-consistent interest rate r in this case follows from equating

$$\varphi H_0 = \mathbb{E}(M_T L_T), \tag{3.10}$$

with φH_0 given by (3.9). This yields (after canceling C from both sides):

$$\sum_{t=0}^{T_{\max}-1} \mathbb{P}(T>t) \cdot P_0^{(t)} = \sum_{t=1}^{T_{\max}} \mathbb{P}(T=t) \cdot P_0^{(t)} \cdot \left(\sum_{s=1}^{t} (1+r)^s \right). \tag{3.11}$$

3.3.3 Pricing the Guarantee

In this section we discuss the approaches that we consider to determine the price of the *NNEG*, given that r is set equal to the market-consistent rate for the loan without the guarantee ((3.7), (3.8), or (3.11)).

If the lender offers a *NNEG*, she runs the risk that the value of the net revenue from selling the property at contract termination, after transaction costs, is lower than the outstanding debt. The lender then effectively acts as a guarantor who will cover the amount NN_T from (3.2) on date T. Assuming market-consistent pricing, the date-zero price of the guarantee is:

$$\begin{aligned}\pi_{NN} &= \mathbb{E}\left[\max\left\{L_T - (1-\delta)\cdot H_T, 0\right\}\cdot M_T\right] \\ &= \sum_{t=1}^{T_{\max}} \mathbb{E}\left[\max\left\{L_t - (1-\delta)\cdot H_t, 0\right\}\cdot M_t | T=t\right]\cdot \mathbb{P}(T=t),\end{aligned}$$

where L_T is the loan balance on date T, given by (3.3), (3.4), or (3.5) depending on the type of reverse mortgage, and where M_T denotes the stochastic discount factor on date T. Because we assume that T is independent of (H_t, M_t), the market price of the guarantee is:

$$\pi_{NN} = \sum_{t=1}^{T_{\max}} \widetilde{\pi}_{NN}(t)\cdot \mathbb{P}(T=t), \tag{3.12}$$

where $\widetilde{\pi}_{NN}(t) = \mathbb{E}\left[\max\left\{L_t - (1-\delta)\cdot H_t, 0\right\}\cdot M_t\right]$ denotes the time $t=0$ price of the guarantee (exactly) ending at date t. For each of the three reverse mortgage designs, the value of $\widetilde{\pi}_{NN}(t)$ depends on the joint distribution of the house price H_t and the stochastic discount factor (SDF) M_t.

In the next section we will consider two approaches to determine the value of $\widetilde{\pi}_{NN}(t)$ by treating it as a put option:

- The GBM model: we price the *NNEG* in a Black-Scholes world.
- The (VAR) model: we derive the joint distribution of the SDF process M_t and the house price process H_t in the context of a Vector AutoRegression (VAR) model. The value of the *NNEG* is then determined via simulation.

3.4 Pricing with the GBM model

3.4.1 The *NNEG* in the GBM Model

In the first model, we interpret the house as a dividend paying asset in continuous time. Assuming the dividend rate is q and the house price and the SDF follow a Geometric Brownian Motion, the *NNEG* can be priced as a Black-Scholes (European) put option on the net house price. Indeed, at contract termination, payments to the lender are capped by the net value of the house. As long as the net house value is above the loan balance, the value of the *NNEG* will be zero. Only when the net house value falls below the loan balance, the guarantee will have material effect. Thus, the *NNEG* is a put option with strike price equal to the loan balance and with the net house price as the underlying asset. The value of the option conditional on $T = t$ is:

$$\begin{aligned} \widetilde{\pi}_{NN}(t) &= \mathbb{E}\left[\max\left\{L_t - (1-\delta)\cdot H_t, 0\right\}\cdot M_t\right] \\ &= \text{BSput}\left((1-\delta)H_0, L_t, r_f, q, t, \sigma\right), \end{aligned} \tag{3.13}$$

where

- r_f is the risk-free rate, σ is the volatility of the house price, q is the dividend rate, and L_t is the loan balance on date t given, by (3.3), (3.4), or (3.5) depending on the type of reverse mortgage;
- the house price H_t is given by $H_t = H_0 \exp\left(\mu t - \frac{1}{2}\sigma^2 t + \sigma W_t\right)$, with $W_t \sim N(0,t)$;
- the SDF M_t is given by $M_t = \exp\left(-r_f t - \frac{1}{2}\lambda^2 t - \lambda W_t\right)$, with $\lambda = (\mu + q - r_f)/\sigma$;
- $\text{BSput}\left(S_0, K, r_f, q, \tau, \sigma\right)$ is the Black-Scholes price of a put option with initial value S_0 of the underlying, strike K, risk free rate r_f, dividend rate q, maturity τ, and volatility σ.

3.4.2 Calibration of the GBM Model

The price of the guarantee in the GBM model depends on the dividend rate q, the proportional transaction cost δ, the volatility of the house price σ, and the probability distribution of the contract termination date T. It also depends on the loan balance L_t for all $t \leq T_{\max}$. For the lump-sum contract and the tenure contract, the loan balance depends on the market-consistent mortgage rate r (from (3.7) and (3.11)), which in turn depends on the term structure of interest rates and the probability distribution

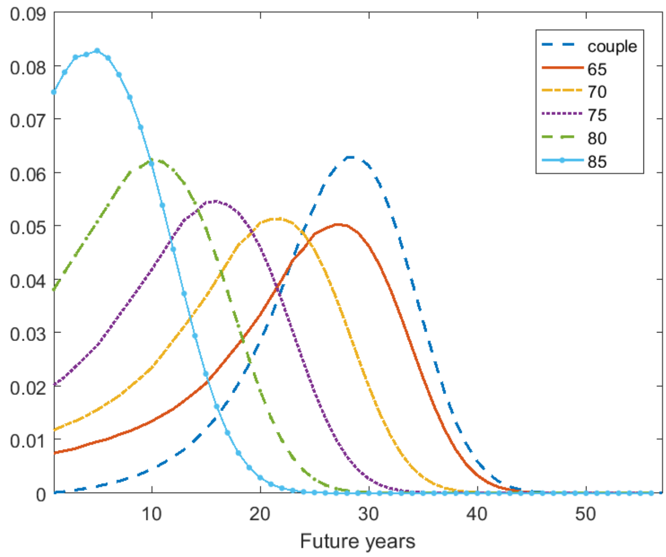


Figure 3.1: This figure displays $\mathbb{P}(T = t)$, the probability distribution of termination date T, for single individuals of different ages, and for a couple with a male aged 67 and a female aged 64.

of the contract termination date T. In this section, we discuss the calibration of these parameters.

δ and σ – The transaction cost in case of a forced sale is set equal to $\delta = 30\%$.[2] The volatility of the house price growth rate is calibrated based on the log return of the Dutch House Price Index from the first quarter of 1996 to the second quarter of 2014. This yields $\sigma = 7\%$.

The probability distribution of T – To determine the probability distribution of T, we use the survival rates published by the Dutch Actuarial Society (AG) in their AG2014 cohort life table. Figure 3.1 displays $\mathbb{P}(T = t)$ for single individuals of different ages, and for a couple with a male aged 67 and a female aged 64.

Risk free rate r_f and mortgage rate r – In the GBM model, the term structure is flat at the risk free rate r_f. To determine this risk free rate r_f (which we shall call the "equivalent risk free rate"), we consider the yield curve determined by the VAR model (see Section 3.5.1), and we let r_f be equal to the yield corresponding to the expected duration of the reverse mortgage contract in the lump sum and interest only contract, while in the tenure contract, we let r_f be equal to the average yield from the first period to the expected duration of the reverse mortgage contract. The expected duration of the contract is determined as the weighted average of the contract ending

[2]Nederlandse Vereniging van Banken: The Dutch Mortgage Market, 26 May 2014.

times, with the weight of each time equal to $P(T = t)$, the contract termination probability at the corresponding time. The market consistent interest rates then follow from solving (3.7), (3.8), and (3.11), with $P_0^{(t)} = \frac{1}{(1+r_f)^t}$. With a constant equivalent risk-free rate, the market consistent interest rate is equal to this equivalent risk-free rate (since $r = r_f$ solves equation (3.7), (3.8) and (3.11)). The equivalent risk free rate r_f and the market-consistent mortgage rate r depend on the age(s) of the borrower, as these determine the expected duration. The results are displayed in Table 3.2. The corresponding loan balance as a function of time is displayed in Figure 3.2 for the three types of reverse mortgages.

	couple	65	70	75	80	85
Lump-sum	0.819%	0.815%	0.805%	0.794%	0.772%	0.744%
Interest-only	0.819%	0.815%	0.805%	0.794%	0.772%	0.744%
Tenure	0.742%	0.732%	0.711%	0.686%	0.649%	0.604%

Table 3.2: This table presents the risk free rates (r_f), which are also the market-consistent mortgage rates (r), in the GBM model for buyers with different ages in the the three types of reverse mortgage schemes.

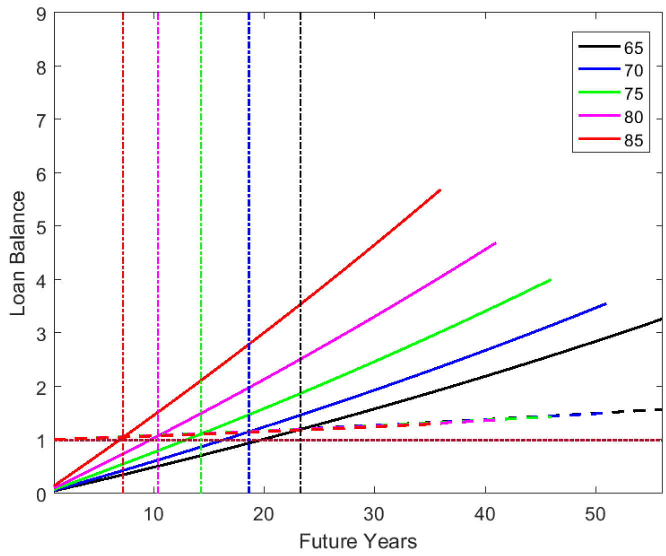


Figure 3.2: The loan balance as a function of t, with L_0 normalized to 1. The dashed line, dotted line, and solid lines represent loan balances for different borrowers in the lump-sum scheme, the interest-only scheme, and the tenure scheme, respectively. The vertical dash-dotted lines represent the expected remaining lives of the borrowers, which are also the expected durations of the contract.

φ	1	3	5	6	10	15	20	30
0%-67%	1.25%	1.25%	1.25%	1.8%	1.88%	2.30%	2.7%	3.45%
68%-88%	1.45%	1.45%	1.45%	2.0%	2.08%	2.5%	2.9%	3.65%
89%-98%	1.75%	1.75%	1.75%	2.3%	2.38%	2.80%	3.2%	3.95%
99%+	2.05%	2.05%	2.05%	2.60%	2.68%	3.10%	3.5%	4.25%

Table 3.3: This table displays the mortgage rates (r) of Florius for different loan-to-value ratios and terms of maturity. These data are obtained from the website of Florius on 8 April 2016.

Dividend rate q − To calibrate the value of the dividend rate q, we use data on interest rates for regular mortgages offered by Florius. Table 3.3 displays the interest rate of Florius for different loan-to-value ratios (φ) and terms of maturity. The interest rate is not linearly but stair-step increasing with the loan-to-value ratio. We focus on mortgages with $\varphi = 67\%$ and $\varphi = 98\%$ in the calibration of the dividend rate q. We determine the model-implied interest rates for these two values of φ (also taking into account that in the real world the mortgage rate r will include a mark-up). We then determine the lower bound for q such that the model-implied interest rates are no larger than the Florius interest rates and for all maturities, and the upper bound for q such that the model-implied interest rates are no less than the Florius interest rates for all maturities, i.e., we let

$$\begin{aligned} q_{\min} &= \max \left\{ q : R(q, \varphi, T_m) \le R^{\mathit{Florius}}(\varphi, T_m) \text{ for all } \varphi, T_m \right\}, \\ q_{\max} &= \min \left\{ q : R(q, \varphi, T_m) \ge R^{\mathit{Florius}}(\varphi, T_m) \text{ for all } \varphi, T_m \right\}, \end{aligned}$$

where $R(q, \varphi, T_m)$ denotes the model-implied market-consistent interest rates for mortgages with loan-to-value ratio φ and term to maturity T_m. In the calibration we consider $\varphi \in \{67\%, 98\%\}$ and $T_m \in \{10, 15, 20\}$. The details of the procedure (including our choice of mark-ups) are discussed in the Appendix.[3] Figure 3.3 presents $R(q, \varphi, T_m)$ as a function of the time-to-maturity in the GBM model with q equal to its upper or lower bound. We find $q_{\min} = 4.6\%$ and $q_{\max} = 6.6\%$. We set the calibrated value of q equal to $(q_{\min} + q_{\max})/2$.

3.4.3 Sensitivity Analysis

In this section, we investigate the sensitivity of the price of the *NNEG*, π_{NN}, to the various parameter values. The sensitivities of $\widetilde{\pi}_{NN}(t)$ follow straightforwardly from

[3] `https://www.hypotheeklastencalculator.nl/berekenen/executiewaarde/`

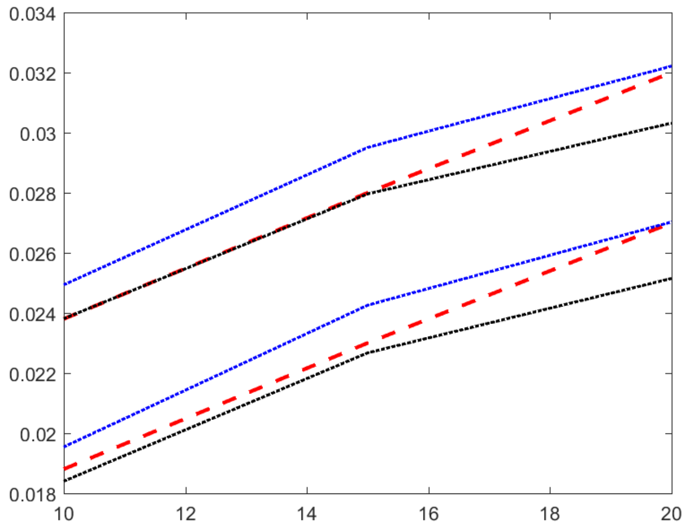


Figure 3.3: This figure displays $R(q, \varphi, T_m)$ as a function of the term to maturity of regular mortgage T_m, for $q = q_{\min}$ and for $q = q_{\max}$ in the GBM model. The dashed lines represent the interest rates of Florius and the dotted lines represent the model-implied interest rate. The lines from the top to the bottom are $R(q_{\max}, 98\%, T_m)$, $R^{Florius}(98\%, T_m)$, $R(q_{\min}, 98\%, T_m)$, $R(q_{\max}, 67\%, T_m)$, $R^{Florius}(67\%, T_m)$, and $R(q_{\min}, 67\%, T_m)$, respectively.

the "Greeks," see, for example, Hull (2015). The sensitivity of π_{NN} then follows from (3.12). We first present the partial derivatives of $\widetilde{\pi}_{NN}(t)$ with respect to the various parameters. Then we illustrate graphically the sensitivities of π_{NN} with respect to these parameters.

To present the partial derivatives of $\widetilde{\pi}_{NN}(t)$, we first notice that BSput $(S_0, K, r_f, q, \tau, \sigma)$, with $S_0 = (1-\delta)H_0$, $K = L_t$, and $\tau = t$, is given by

$$\text{BSput}\left((1-\delta)H_0, L_t, r_f, q, t, \sigma\right) = e^{-rt} L_t \Phi(-d_2) - (1-\delta)H_0 e^{-qt} \Phi(-d_1),$$

with

$$d_1 = \frac{\log((1-\delta)H_0/L_t) + (r_f - q + \sigma^2/2)t}{\sigma\sqrt{t}},$$

$d_2 = d_1 - \sigma\sqrt{t}$ and where Φ is the cumulative distribution function of the standard normal distribution.

The partial derivatives of $\widetilde{\pi}_{NN}(t)$ with respect to the loan-to-value ratio φ, the dividend rate q, the transaction costs δ, and the house price volatility σ are given by

$$\frac{\partial \widetilde{\pi}_{NN}(t)}{\partial \varphi} = e^{-r_f t}\Phi(-d_2) \times \frac{\partial L_t}{\partial \varphi},$$
$$\frac{\partial \widetilde{\pi}_{NN}(t)}{\partial q} = t(1-\delta)H_0 e^{-qt}\Phi(-d_1),$$
$$\frac{\partial \widetilde{\pi}_{NN}(t)}{\partial \delta} = e^{-qt}H_0\Phi(-d_1),$$
$$\frac{\partial \widetilde{\pi}_{NN}(t)}{\partial \sigma} = (1-\delta)H_0 e^{-qt}\phi(d_1)\sqrt{t},$$

where $\partial L_t/\partial\varphi$ depends on the reverse mortgage scheme and where ϕ is the density function of the standard normal distribution. These partial derivatives are all positive, implying that $\widetilde{\pi}_{NN}(t)$ and thus also π_{NN} are increasing functions of these parameters.

These positive partial derivatives can easily be understood using the characteristics of the underlying put option. For example, an increase in the loan-to-value ratio φ results in an increase in the strike price of the put option, which leads to a higher put option price. An increase in the dividend rate q results in an increase in the risk premium (i.e., $\lambda = (\mu + q - r_f)/\sigma$). This yields a more widespread distribution of the SDF M_t, resulting in a higher put option price. An increase in the transaction costs δ means a decrease in the underlying value $(1-\delta)H_0$. But the delta (Δ) of a put option (i.e., the sensitivity of the put option price with respect to the underlying) is negative, so that an increase in δ has a positive effect on the put option price. Finally, an increase in the house price volatility σ is positive, following from vega (i.e., the sensitivity of the put option price with respect to the volatility) being positive.

The second order partial derivatives are given by

$$\frac{\partial^2 \widetilde{\pi}_{NN}(t)}{\partial \varphi^2} = e^{-r_f t}\phi(d_2)\frac{\partial \log L_t(\varphi)}{\partial \varphi}\frac{\partial L_t(\varphi)}{\partial \varphi}/\sigma\sqrt{t},$$
$$\frac{\partial^2 \widetilde{\pi}_{NN}(t)}{\partial q^2} = t^2(1-\delta)H_0 e^{-qt}\left(\phi(d_1)/\sigma\sqrt{t} - \Phi(-d_1)\right),$$
$$\frac{\partial^2 \widetilde{\pi}_{NN}(t)}{\partial \delta^2} = e^{-qt}H_0\phi(d_1)/(1-\delta)\sigma\sqrt{t},$$
$$\frac{\partial^2 \widetilde{\pi}_{NN}(t)}{\partial \sigma^2} = \nu d_1 d_2/\sigma,$$

with $\nu = \partial\widetilde{\pi}_{NN}(t)/\partial\sigma$, the partial derivative of $\widetilde{\pi}_{NN}(t)$ with respect to σ (known as the "Greek" vega). The second order partial derivatives with respect to φ and δ are positive, implying that $\widetilde{\pi}_{NN}(t)$ and thus also π_{NN} are convex functions of φ and δ. On the other hand, the second order partial derivatives with respect to q and σ can be both positive and negative. This implies that $\widetilde{\pi}_{NN}(t)$ can be both accelerating and decelerating as function of q and σ, depending on the parameter values.

In Figure 3.4, we illustrate graphically π_{NN} as a function of the loan-to-value ratio (φ, first row), the dividend rate (q, second row), the proportional transaction cost (δ, third row), and the volatility of the house price (σ, last row), with $\varphi \in [0,1]$, and with the latter three parameters around their calibrated values. The left panels correspond to the the lump sum contract, the middle panels to the interest-only contract, and the right panels to the tenure contract. In each case, results are displayed for single borrowers of different ages. If φ is fixed, we set it equal to $\varphi = 0.50$. If any of the other three parameters is kept fixed, its value is set equal to its calibrated value. The initial house price is set equal to $H_0 = 1$. Figure 3.5 complements Figure 3.4 by showing the second order partial derivatives with respect to φ and q as a function of φ and q, respectively, and by showing $\partial^2\widetilde{\pi}_{NN}(t)/\partial\varphi\partial q = \partial^2\widetilde{\pi}_{NN}(t)/\partial q\partial\varphi$ as a function of φ and q. This latter second order derivative is given by

$$\frac{\partial^2\widetilde{\pi}_{NN}(t)}{\partial\varphi\partial q} = te^{-r_f t}\phi(d_2)\frac{\partial L_t(\varphi)}{\partial\varphi}/\sigma\sqrt{t}.$$

All curves in Figure 3.4 are increasing as follows from the positive partial derivatives of $\widetilde{\pi}_{NN}(t)$. Their shapes can be understood by taking into account the second order partial derivatives. For the same parameter values, the curves for older buyers typically correspond to lower values of π_{NN}. Older buyers have a higher probability of shorter remaining lifetimes. This would suggest a higher value, since theta (i.e., the sensitivity of the standard put option price with respect to the time-to-maturity, with symbol Θ) is typically negative, except for deep in-the-money put options. However, there are two opposing effects. First, we have an effect via the strike price. Increasing the time-to-maturity, increases this strike price (except in the interest only contract), which has a positive effect on the put option value. Secondly, we have an effect via the risk free interest rate: older buyers have a lower risk free interest rate (see Table 3.2). Since rho (i.e., the sensitivity of the standard put option price with respect to the risk free interest rate) is negative, a lower risk free rate implies a higher value of the put option. The graphs show the resulting net age effects. In most cases the two positive effects (via the strike price and the risk free interest rate) dominate the negative time effect (via Θ), except for the tenure contract with very low dividend yields. The age effect is stronger in the lump sum case than in the interest only case. This can be understood as follows. The lump sum and the interest only contract have the same risk free rates, so an important difference in terms of the age effect between

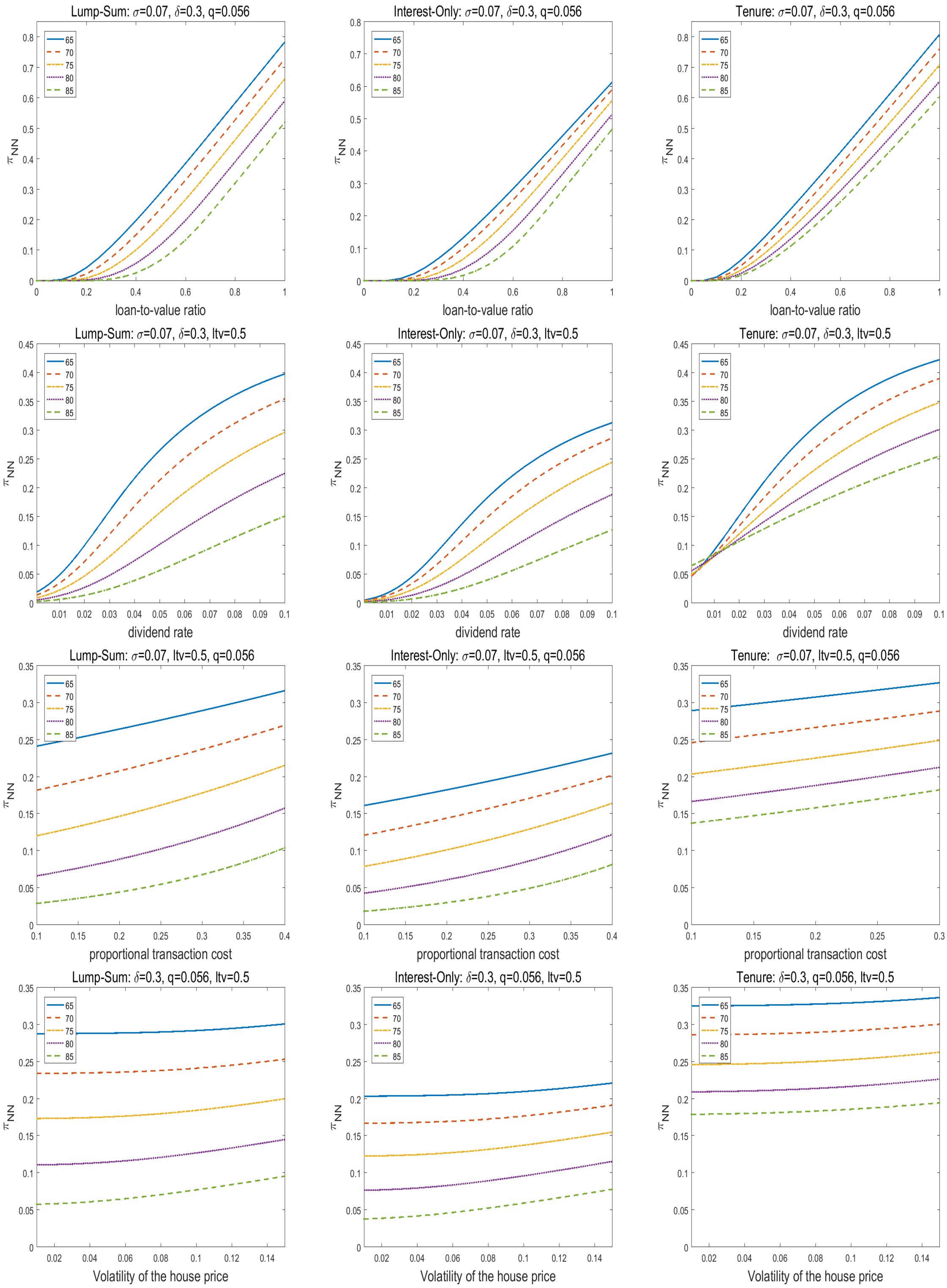


Figure 3.4: Sensitivity analyses of π_{NN} for the lump-sum scheme (left), the interest only scheme (middle) and the tenure scheme (right). Diagrams from the first row to the fourth row show the sensitivity of π_{NN} with respect to the loan-to-value ratio (ltv), the dividend rate (q), the proportional cost (δ), and the house price volatility (σ), respectively.

these two is the positive strike effect, which is present in the lump sum but absent in the interest only contract. The tenure contract has a lower risk free interest rates than the other two contracts (see Table 3.2), so that here the magnitude of the net age effect compared to the other two is not immediately clear, but can be observed from the figure (given the considered parameter values).

Among these calibrated parameters (dividend rate (q), proportional transaction costs (δ), and volatility of the house price (σ)), π_{NN} seems to be most sensitive to the dividend rate. For example, π_{NN} for a 65-year-old borrower increases from 1.68% to around 39.8% as the dividend rate increases from 0% to 10% in the lump-sum scheme. In the interest-only scheme, π_{NN} only increases from 0.01%% to 17.35% and in the tenure scheme, it increases from 4.21% to 42.28%.

3.5 Pricing with the VAR model

In this section we consider an alternative approach to model the joint distribution of (H_t, M_t). This approach makes use of a Vector Auto Regression (VAR) model that includes the GBM model as a special case. We first present the VAR model, the corresponding SDF, and the implied term structure. Next, we discuss the parameter estimation and calibration. We conclude this section by illustrating the pricing of the *NNEG* (i.e., π_{NN}).

3.5.1 The VAR Model

Five variables in total will be included in the VAR model: the Dutch GDP log growth rate, the log return on the Dutch House price index (which reflects the growth rate of house prices), inflation (quantified as the log price change in the CPI index), the 3 months Euribor rate, and the spread of the 10 years zero coupon rate over the 3-months Euribor rate. Table 3.4 presents the variable names and a short description of each of the variables. These choices are motivated by the literature. Brooks and Tsolacos (1999) indicated that interest and inflation are significant factors in explaining house price returns. Abelson et al (2005) estimated a model using several economic variables. They found that in the long run house prices are affected significantly by disposable income, interest rates, equity prices, consumer price indexes, and the supply of housing. Ang and Piazzesi (2003) describe the joint dynamics of bond yields and macroeconomic variables in a VAR model. They include GDP as a factor in predicting housing prices and the yield curve. Following this study, we also

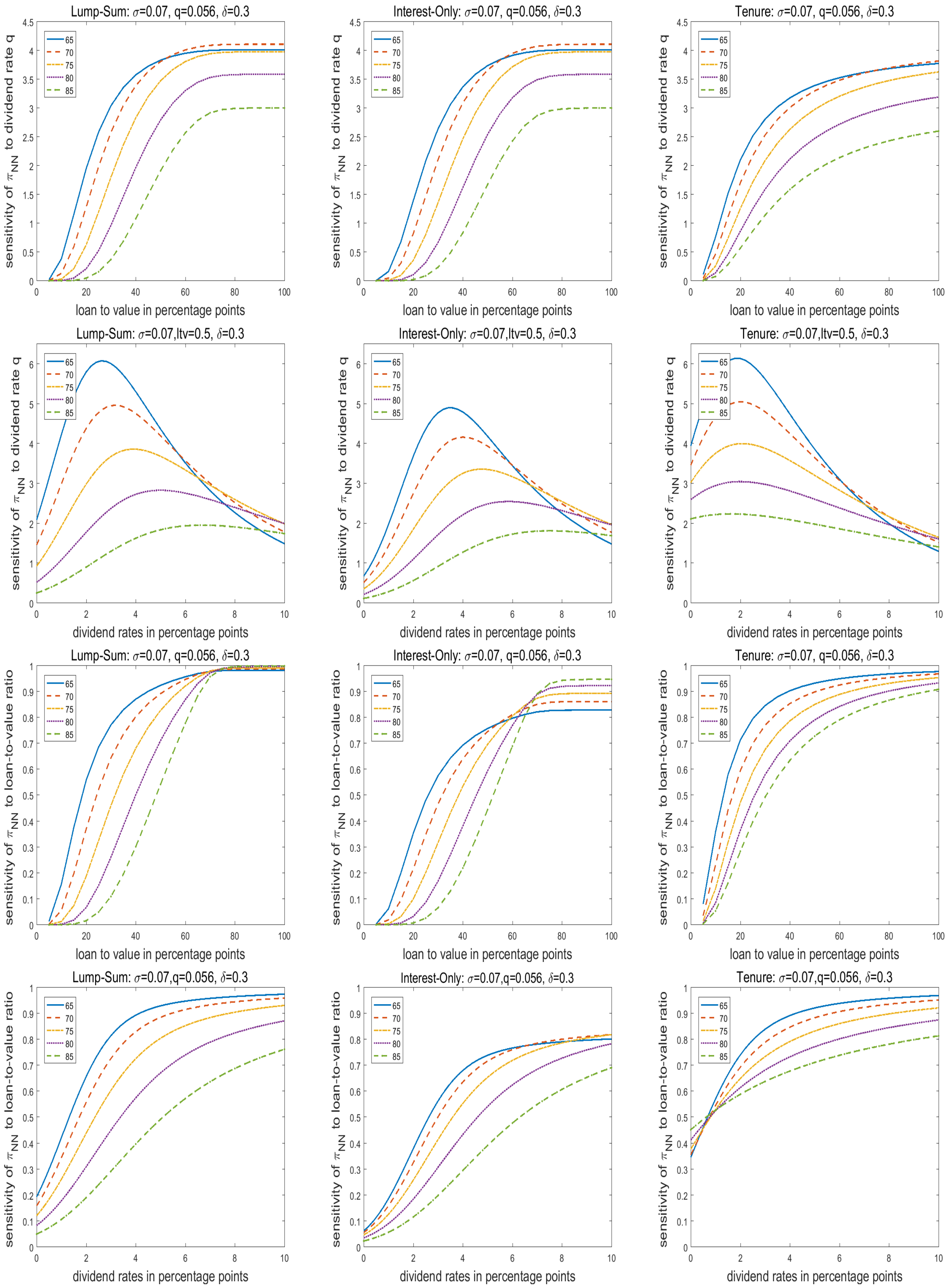


Figure 3.5: Sensitivity analysis of the derivative of π_{NN} for the lump-sum scheme (left), the interest only scheme (middle) and the tenure scheme (right). The transaction cost $\delta = 0.3$, and the volatility of the house price increasing rate $\sigma = 0.07$. Diagrams from the first row to the fourth row show the sensitivity of $\partial\pi_{NN}/\partial q$ with respect to the loan-to-value ratio (φ), the dividend rate (q), the sensitivity of $\partial\pi_{NN}/\partial\varphi$ with respect to the loan-to-value ratio (φ), the dividend rate (q), respectively.

include GDP and inflation in our VAR model. In line with recent studies (Sherris and Sun (2010), Alai et al (2013), Shao et al (2012) and Cho et al (2013)) we will use two factors from the yield curve, namely, the three months Euribor rate and the ten year spread.

variable	definition
hpi	house price growth rate
gdp	GDP growth rate
cpi	inflation
$y^{(1)}$	3-month zero-coupon rate
$y^{(40)} - y^{(1)}$	10-year yield spread

Table 3.4: This table presents the state variables used in the VAR model.

The dynamics of the five state variables, collected in the n-dimensional vector x_t, with $n = 5$ in our case, is assumed to follow the following VAR:

$$x_{t+1} = \alpha + \Gamma x_t + \Sigma \varepsilon_{t+1}, \quad \varepsilon_{t+1} \overset{i.i.d}{\sim} N(0_{n\times 1}, I_{n\times n}), \tag{3.14}$$

where α is an n-vector of parameters, Γ is an $n \times n$-dimensional matrix of parameters, Σ an $n \times n$-dimensional lower triangular matrix, and ε_{t+1} is an n-dimensional vector of error terms representing the shocks to the system.

For $\Gamma = 0$, we would find for H_t

$$H_t = H_0 \exp\left(\alpha_1 + \sigma_1 \sum_{s=1}^{t} \epsilon_{1,s}\right), \tag{3.15}$$

with α_1 the first component of α, σ_1 the $(1,1)$-component of Σ, and $\epsilon_{1,s}$ the first component of ϵ_s. Thus, this house price process is similar to the house price process we used in the GBM (using $\alpha_1 = \mu - \frac{1}{2}\sigma_1^2$), implying that the VAR-model, with $\Gamma \neq 0$, generalizes the GBM house price process.

3.5.2 The Stochastic Discount Factor

The SDF M_t is given by $M_t = \prod_{s=1}^{t} m_s$, where $m_s > 0$ is the SDF between periods $s-1$ and s, i.e., for a payoff X_s at time s the price S_{s-1} at time $s-1$ is given by

$$S_{s-1} = \mathbb{E}_{s-1}(m_s X_s),$$

with $\mathbb{E}_{s-1}$ the conditional expectation operator, conditional upon the information available at time $s-1$. For a payoff X_t at time t, the price at time $t = 0$ can be obtained by iterating this equation backward, also using the law of the iterated expectations, resulting in

$$S_0 = \mathbb{E}\left(\prod_{s=1}^{t} m_s X_t\right) = \mathbb{E}(M_t X_t),$$

with $\mathbb{E} = \mathbb{E}_0$.

We model m_{t+1} to be exponentially affine:

$$m_{t+1} = \exp\left(-y_t^{(1)} - \frac{1}{2}\lambda'\lambda - \lambda'\varepsilon_{t+1}\right), \tag{3.16}$$

with $y_t^{(1)}$ the one-period (continuously compounded) interest rate and λ an n-dimensional vectors of parameters (the "prices of idiosyncratic risk"). Given m_{t+1}, we find the SDF M_t:

$$M_t = \prod_{s=1}^{t} m_s = \exp\left(-\sum_{s=1}^{t} y_s^{(1)} - \frac{1}{2}\lambda'\lambda t - \lambda' \sum_{s=1}^{t} \epsilon_s\right). \tag{3.17}$$

Here, $\sum_{s=1}^{t} \epsilon_s$ follows a n-dimensional normal distribution with mean vector 0 and covariance matrix tI_n, with I_n the n-dimensional identity matrix. Thus, this SDF M_t generalizes the SDF that we use in the GBM model.

3.5.3 The (Implied) Term Structure

The (nominal) term structure can be derived from the yields of the zero-coupon bonds. Define the yield to maturity of a zero-coupon bond with time-to-maturity $\mathbb{T}$ as $y_t^{(\mathbb{T})}$, then we have

$$P_t^{(\mathbb{T})} = \exp(-\mathbb{T} y_t^{(\mathbb{T})}).$$

A $\mathbb{T}$-year zero coupon bond, like any payoff in the economy, can be priced by the SDF. Therefore, the price of this zero coupon bond at time t satisfies,

$$P_t^{(\mathbb{T})} = \mathbb{E}_t\left(m_{t+1} P_{t+1}^{(\mathbb{T}-1)}\right) \tag{3.18}$$

For $\mathbb{T} = 1$ we have

$$y_t^{(1)} = -\log(P_t^{(1)}) = -\log\left(\mathbb{E}_t\left(m_{t+1} \times 1\right)\right) = -\log\exp\left(-y_t^{(1)}\right) = y_t^{(1)},$$

showing that the model is self-consistent.

By postulating

$$\log(P_t^{(\mathbb{T})}) = -A(\mathbb{T}) - B(\mathbb{T})' x_t, \tag{3.19}$$

$A(\mathbb{T})$ and $B(\mathbb{T})$ can be solved recursively using this equation. This results in the following equations:

$$\begin{aligned} A(\mathbb{T}) &= A(\mathbb{T}-1) + B(\mathbb{T}-1)'\alpha - \tfrac{1}{2}B(\mathbb{T}-1)'\Sigma\Sigma' B(\mathbb{T}-1) - B(\mathbb{T}-1)'\Sigma\lambda \\ B(\mathbb{T}) &= \Gamma' B(\mathbb{T}-1) + \delta_1, \end{aligned} \tag{3.20}$$

with $\delta_1 = (0,0,0,1,0)'$, selecting the fourth component of x_t, which is $y_t^{(1)}$. The starting values for A and B are $A(0) = 0$, $B(0) = 0_n$ (following from $\log P_t^{(0)} = \log(1) = 0$). The zero-coupon yields are thus given by

$$y_t^{(\mathbb{T})} = a(\mathbb{T}) + b(\mathbb{T})' x_t, \tag{3.21}$$

with $a(\mathbb{T}) = -A(\mathbb{T})/\mathbb{T}$ and $b(\mathbb{T}) = -B(\mathbb{T})/\mathbb{T}$.

3.5.4 Data

For the five state variables, we use data retrieved from Datastream and the Dutch Central Bank (DNB), from the first quarter of 2009 up to and including the first quarter of 2016. Figure 3.6 shows the evolution of the five state variables since the second quarter of 1995, when the HPI growth rate became available. Since the GDP growth rate is only available quarterly, we use quarterly data. There was a change in the evolution pattern during the financial crisis, especially for the 3-month rate and the HPI growth rate. Both of them are essential in the pricing of the *NNEG*. To better deal with the impact of the low interest rate and house price growth rate, we use the subsample after the financial crisis in our estimation (i.e., starting from the first quarter of 2009).

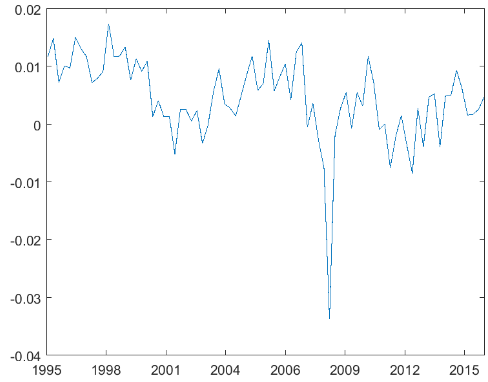
In the calibration to the prices of idiosyncratic risk (the parameter vector λ) we make use of interest rates, downloaded from the website of the European Central Bank.[4] We use the three-month, nine-month, and one-year to thirty-year interest rates from the third quarter of 2014 to the first quarter of 2016.

3.5.5 Estimation and Calibration

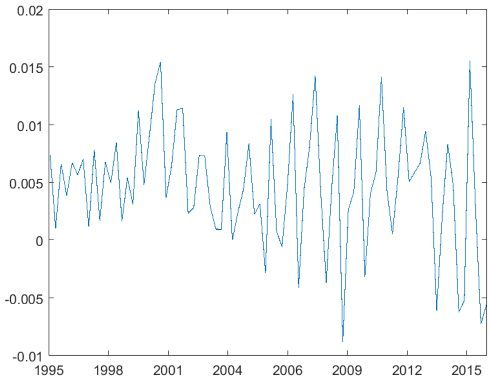
In line with the existing literature (Ang and Piazzesi, 2004; Cochrane and Piazzesi, 2005 and 2008), we conduct a two-step estimation procedure to determine the parameters of the VAR model and the SDF. In the first step, we estimate the VAR model using maximum likelihood. In the second step, we treat the estimated parameters in the VAR model as given, and calibrate λ, the vector of the price of idiosyncratic

[4]See `http://www.ecb.europa.eu/stats/money/yc/html/index.en.html`.

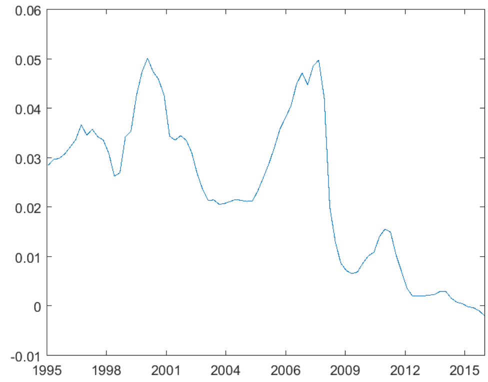
(a) HPI growth rate



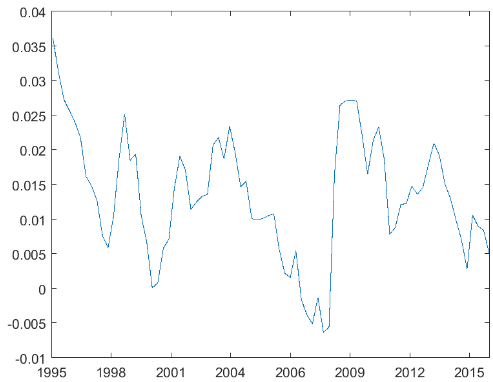
(b) GDP growth rate



(c) Inflation



(d) 3-month rate



(e) 10-year spread

Figure 3.6: These figures display the historical movements of the state variables in the VAR model. The caption under each figure indicates the name of the corresponding state variable.

risk, by minimizing the squared difference between the model-implied term structure of interest rates (as function of λ) to the historical term structure of interest rates. The first step estimation results are shown in Table 3.5. The calibrated values for the price of the idiosyncratic risk parameters are shown in the second and third columns (columns "original 1" and "original 2") of Table 3.6. In case of "original 1" we do not impose restrictions on λ. In case of "original 2" we assume only the inflation, short rates, and 10-year rate spreads have a non-zero price of idiosyncratic risk. This means that this calibrated version of the VAR model does not include the GBM model as special case.

	α			Γ		
hpi	-0.00196	0.39646	0.2496	-0.26041	-3.68573	1.37647
	0.00401	*0.14667*	*0.24664*	*0.27633*	*1.52411*	*1.06391*
gdp	-0.00636	0.22988	0.07766	-0.0519	-0.0393	2.25398
	0.003	*0.1097*	*0.18447*	*0.20668*	*1.13992*	*0.79572*
cpi	0.00324	-0.06246	-0.14935	-0.04322	0.55684	-0.16527
	0.00276	*0.10074*	*0.1694*	*0.1898*	*1.04681*	*0.73073*
$y^{(1)}$	0.00067	0.0066	0.03084	0.00348	0.86901	-0.12491
	0.00043	*0.01585*	*0.02665*	*0.02986*	*0.16469*	*0.11497*
$y^{(40)} - y^{(1)}$	0.0013	-0.02394	-0.05615	-0.04688	-0.00171	0.69047
	0.00045	*0.01654*	*0.02782*	*0.03117*	*0.1719*	*0.1200*
	$\mu = (I - \Gamma)^{-1}\alpha$			Σ		
hpi	-0.00491	0.00895	0	0	0	0
gdp	0.00103	0.0001	0.0067	0	0	0
cpi	0.00346	-0.00028	-0.00079	0.00609	0	0
$y^{(1)}$	0.00154	-2.63E-05	-0.0008	5.82E-05	0.00054	0
$y^{(40)} - y^{(1)}$	0.00385	-0.00029	-0.00039	0.00016	0.00027	0.00083

Table 3.5: Estimation results of the VAR(1) model $x_{t+1} = \alpha + \Gamma x_t + \Sigma\varepsilon_{t+1}$. The first column contains the state variables. In the first part of this table, the estimated coefficients and the corresponding standard errors are presented. In the second part of this table, the Σ matrix and the model implied quarterly equilibrium rates for the state variables are presented.

For the log return on the house price index we find that it depends positively on its own lag (with coefficient around 0.40) and negatively on the one-year interest rate (with coefficient around -3.7). These effects are statistically significant (at the 5% significance level). The implied long run average of the log return on the house price

	original 1	original 2	middle	lower	upper
hpi	-0.055	0	0	0	0
gdp	0.114	0	0	0	0
cpi	-0.003	-0.0060	-0.0058	-0.0055	-0.0061
$y^{(1)}$	-0.126	-0.2525	-0.2505	-0.2470	-0.2540
$y^{(40)} - y^{(1)}$	-0.008	-0.0162	-0.0163	-0.0166	-0.0161

Table 3.6: This table presents the calibrated λ, the price of risk. The first column contains the name of the risk factors. The calibrated values for the price of the idiosyncratic risk parameters are shown in columns 2 to 6. In the second column (column "original 1"), we do not impose restrictions on λ. In columns 3 to 6, we assume only the inflation, short rates, and 10-year rate spreads have a non-zero price of idiosyncratic risk. The calibrated values in column 2 correspond to the case where the house price increase rate is the one estimated by the VAR model (denoted as μ^h_{hpi}). The calibrated values in columns 4, 5, and 6 correspond to the cases where the house price increase rate equal to the calibrated mortgage based drift (denoted as μ^m_{hpi} later), the lower bound of the drift (denoted as $\mu^m_{\text{hpi,min}}$ later), and the upper bound of the drift (denoted as $\mu^m_{\text{hpi,max}}$ later), respectively.

index (shown in the bottom panel of Table 3.5) turns out to be -0.491%, i.e., around -1.96% on an annual basis. The estimated volatility of the house price index, equal to around 1.8% on an annual basis (i.e., ca. $\sqrt{4}\times 0.895\%$), is lower than the calibrated value of the volatility used in the GBM model, since the estimated volatility is based on a shorter sample, starting from the first quarter of 2009.

In the GBM model this long run average does not play a role in the pricing of the *NNEG* (as it does not appear in the Black Scholes put option formula). However, contrary to the GBM model, this parameter and the related (conditional) mean of the log return on the house price index do play a role in the pricing of the *NNEG* in our version of the VAR model. Indeed, suppose that the house-cum-dividend value $\widetilde{H}_{t+1}$ at time $t+1$ is given by

$$\widetilde{H}_{t+1} = H_{t+1} \exp(q_t), \tag{3.22}$$

with q_t the dividend yield. Then $H_t = \mathbb{E}_t(M_{t+1}\widetilde{H}_{t+1})$ yields,

$$q_t = y_t^{(1)} - \alpha_1 - \frac{1}{2}\sigma_1^2 - \gamma_1' x_t + \lambda_1 \sigma_1, \tag{3.23}$$

with (as before) α_1 the first component of α, σ_1 the $(1,1)$-component of Σ, λ_1 the first component of λ, and with γ_1 the first row of Γ. As discussed in the context of the GBM model, the parameter q_t is an important parameter in the pricing of the

NNEG. The results might be quite sensitive to this parameter. Therefore, like in the GBM model, we shall calibrate q_t, based on observed prices of regular mortgages.

The dividend yield q_t can be calibrated in different ways, for example, by (re) -calibrating one or more of the parameters of the right hand side of (3.23). In this paper we choose to calibrate q_t by (re)calibrating μ^h_{hpi}, the first component of μ, with μ given by $\mu = (I_n - \Gamma)^{-1}\alpha$, and h means the value is estimated using historical house price data. The calibrated value of μ^h_{hpi} results in (re)calibrated values of the whole vector α, using $\alpha = (I_n - \Gamma)\mu$. To re-calibrated μ_{hpi}, we use the same procedure as described for the GBM model. We expect that the re-calibrated value based on regular mortgage data better reflects the risk premium in the house price increase rate than the estimated value based on house price data. To make a distinction between the calibrated value of the house price increase rate based on regular mortgage data and the estimated value of the house price increase rate based on house price data, we refer to the calibrated value (based on the regular mortgage data) as the "mortgage data based drift" and denote it as μ^m_{hpi}, where m means that this drift is based on (regular) mortgage data. Details are available in the Appendix of this chapter. We present the results for the version of our model with only the inflation, short rates, and 10-year rate spreads having a non-zero price of idiosyncratic risk (i.e., version "original 2" in Table 3.6). Figure 3.7 presents the analogue of Figure 3.3, with $R(\mu^m_{\text{hpi}}, \varphi, T_m)$ instead of $R(q, \varphi, T_m)$. We show $R(\mu^m_{\text{hpi}}, \varphi, T_m)$ as a function of the term to maturity of regular mortgages (T_m) with μ^m_{hpi} equal to its upper or lower bound. The figure also displays $R^{Florius}(\varphi, T_m)$ (see Figure 3.3). The resulting calibrated upper and lower bound for μ^m_{hpi} (annualized) are given by:

$$\mu^m_{\text{hpi, min}} = -4.99\% \text{ and } \mu^m_{\text{hpi, max}} = -1.14\%.$$

This corresponds to $q_{min} = 1.12\%$ and $q_{max} = 4.97\%$ (setting $q_t = -\mu^m_{\text{hpi}} - \frac{1}{2}\sigma_1^2 + y_t^{(1)}$, with $y_t^{(1)} = 0$, using annualized parameter values). Thus, there is some (minor) overlap with the range found in the GBM model. We set the mortgage data based drift of the annualized μ^m_{hpi} equal to the average of the upper and lower bound drifts:

$$\mu^m_{\text{hpi}} = (\mu^m_{\text{hpi, min}} + \mu^m_{\text{hpi, max}})/2 = -3.065\%.$$

This mortgage data based drift is substantially lower than the estimated value (equal to -1.96%). However, the estimated value lies between the lower and upper bound.

With the mortgage data based drift of the house price growth rate μ^m_{hpi} and the corresponding constant terms α, we re-calibrated the prices of idiosyncratic risk λ

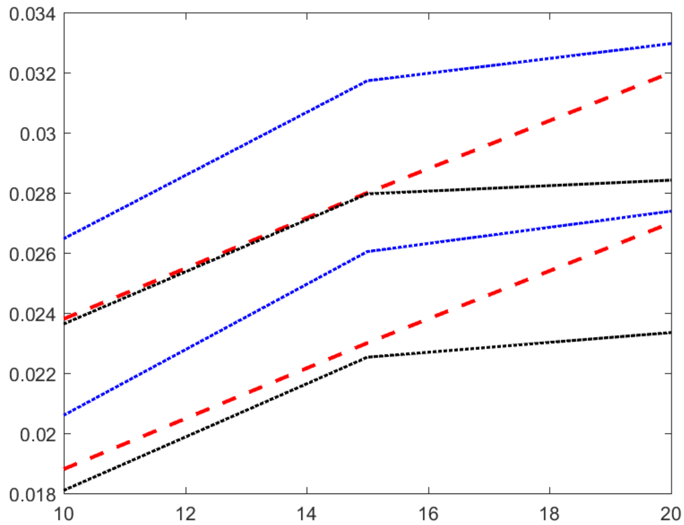


Figure 3.7: This figure displays $R(q, \varphi, T_m)$ as a function of T_m, for $\mu_{\text{hpi}} = \mu_{\text{hpi,min}}$ and for $\mu_{\text{hpi}} = \mu_{\text{hpi,max}}$ in the VAR model. The dashed lines represent the interest rates of Florius and the dotted lines represent the model-implied interest rate. The lines from the top to the bottom are $R(\mu_{\text{hpi,min}}, 98\%, T_m)$, $R^{Florius}(98\%, T_m)$, $R(\mu_{\text{hpi,max}}, 98\%, T_m)$, $R(\mu_{\text{hpi,min}}, 67\%, T_m)$, $R^{Florius}(67\%, T_m)$, and $R(\mu_{\text{hpi,max}}, 67\%, T_m)$, respectively.

to derive the SDF corresponding to the mortgage data based drift, the upper and the lower bound of μ^p_{hpi}. In this way, by not re-calibrating just a single (*ad hoc*) parameter, we aim to avoid disturbing the links between the different parts of the model. Table 3.6, columns "middle," "lower," and "upper" show the resulting values of λ for μ^m_{hpi} equal to its mortgage data based drift, and to its lower and upper limit, respectively.

Finally, we make the same assumptions with respect to T as in the GBM model. Also the value of δ is chosen as in the GBM model.

3.5.6 Pricing the *NNEG*

We can now price the *NNEG* with the VAR model. We use the end-of-sample term structure of interest rates according to the VAR model, given by equation (3.21) with x_t equal to the state variables in the last period of the sample. The resulting term structure is displayed in Figure 3.8. The corresponding market-consistent interest rates follow from solving (3.7), (3.8), and (3.11), with $P_0^{(t)} = \exp(-ty^{(t)})^t$. The results are displayed in Table 3.7.

	couple	65	70	75	80	85
Lump-sum	0.819%	0.815%	0.806%	0.793%	0.773%	0.741%
Interest-only	0.816%	0.811%	0.803%	0.790%	0.769%	0.737%
Tenure	0.847%	0.846%	0.844%	0.841%	0.835%	0.823%

Table 3.7: This table contains the market-consistent mortgage rates in the VAR model for different buyers in the three reverse mortgage schemes.

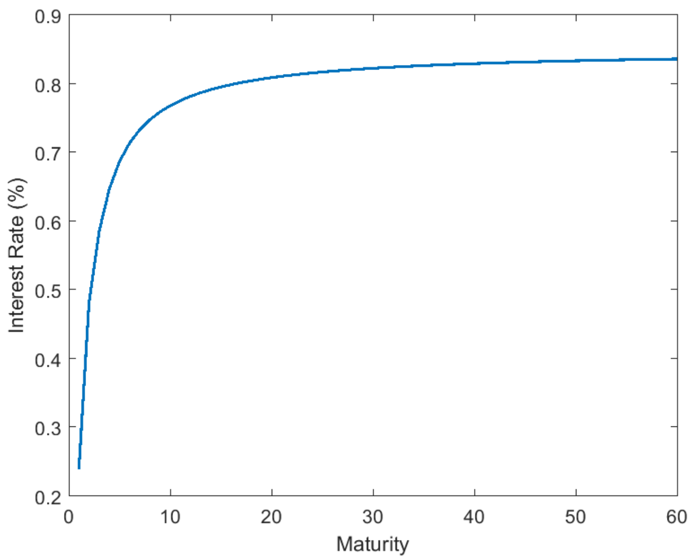


Figure 3.8: This figure displays the term structure of interest rate in the VAR model. This is also the term structure of interest rates used in the derivation of the market-consistent reverse mortgage rates.

We determine the price of the guarantee conditional at time t, i.e.

$$\widetilde{\pi}_{NN}(t) = \mathbb{E}\left[\max\left\{L_t - (1-\delta)\cdot H_t, 0\right\}\cdot M_t\right],$$

via simulation. In our simulation we generate 5000 scenarios for (H_t, M_t). For each scenario, we determine the corresponding value of $\max\{L_t(\varphi) - (1-\delta)\cdot H_t, 0\}\cdot M_t$, and we set $\widetilde{\pi}_{NN}(t)$ equal to the average of these simulated values. Combined with the probability distribution of T, this yields the value of π_{NN} following from (3.12).

In Figure 3.9, we display π_{NN} for the three reverse mortgage products as a function of the two input parameters φ (the effect of the loan-to-value ratio) and δ (the forced sale transaction cost), with the other parameters set to their estimated or calibrated values, and with $H_0 = 1$.

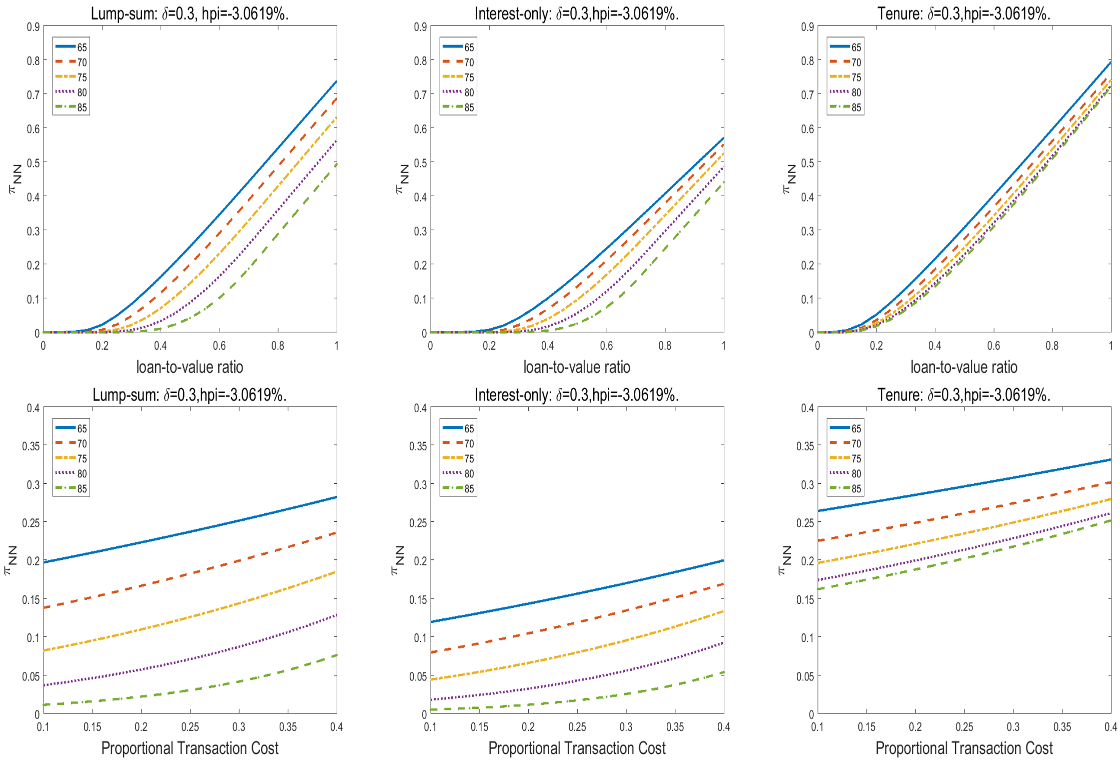


Figure 3.9: Sensitivity analysis of π_{NN} for the lump-sum scheme (left), the interest only scheme (middle) and the tenure scheme (right) in the VAR model. π_{NN} is plotted against the loan-to-value ratio (φ) in the first row and the proportional transaction cost (δ) in the second row.

The interest-only contract yields the lowest π_{NN} value, and the tenure contract yields the highest π_{NN} value. With $\mu^p_{\text{hpi}} = -3.065\%$, for a 65-year-old borrower, π_{NN} is 56.97% for the interest-only scheme when the initial loan-to-value ratio is 100%. The corresponding π_{NN} is around 73.55% for the lump-sum scheme and 79.16% for the tenure scheme.

3.6 Model risk

In the previous sections we discussed two approaches to price the *NNEG*. The results show that among the calibrated/estimated parameters, the value of the *NNEG* seems to be quite sensitive to the dividend rate q in the GBM model, and to the house price growth rate μ_{hpi} in the VAR model. For both these parameters, we have calibrated the range of plausible values using data on regular mortgages. This led to (in annual terms)

$$\begin{aligned} q &\in [4.6\%, 6.6\%], \text{ for the GBM model,} \\ \mu^m_{\text{hpi}} &\in [-4.99\%, -1.14\%], \text{ for the VAR model.} \end{aligned}$$

We note that the mortgage data based drift in the VAR model, μ^p_{hpi}, not only reflects the house growth rate, but also the risk premium.

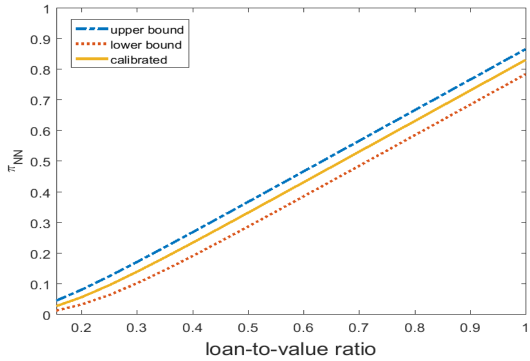
In this section, we compare the ranges of the value of π_{NN} for the GBM model and for the VAR model, resulting from these calibrated ranges of parameters q and μ^p_{hpi}, respectively.

Figure 3.10 and Table 3.8 display the upper bound and the lower bound for π_{NN} for both models, as a function of the loan-to-value ratio. All other parameters are set equal to their calibrated/estimated values, as discussed in Sections 3.4.2 and 3.5.5, respectively. We present results for the case where the borrower is a couple, consisting of a male and a female, with the male 67 years and the female 64. As before, the initial house value is normalized to 1. Figure 3.10 also includes the results using the calibrated value of q in the GBM model (i.e., $q = 5.6\%$) and using the estimated value of μ^h_{hpi} in the VAR model (i.e., $\mu^h_{\text{hpi}} = -1.96\%$).

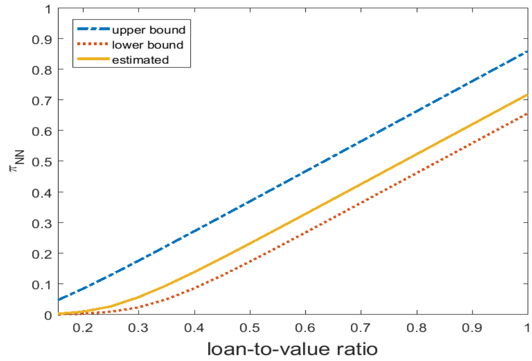
The results show that the difference in the values of π_{NN} between the lower and upper bounds can be quite substantial. For example, for the lump sum contract, we find using the VAR model that the interval of π_{NN} is around $[0\%, 5.4\%]$ for the lowest loan-to-value ratio considered ($\varphi = 15.5\%$), changing to $[24\%, 45\%]$ for the largest loan-to-value ratio considered ($\varphi = 55\%$). The corresponding intervals for the GBM

Lump-sum Scheme				
φ	GBM		VAR	
15.5%	1.320%	4.560%	0.000%	5.370%
20%	3.270%	8.090%	0.070%	9.360%
30%	10.210%	17.160%	2.710%	19.200%
40%	19.090%	26.860%	9.720%	29.500%
50%	28.700%	36.760%	19.130%	39.930%
55%	33.620%	41.740%	24.180%	45.170%
Interest-only Scheme				
φ	GBM		VAR	
15.5%	0.430%	2.390%	0.000%	2.760%
20%	1.330%	4.750%	0.000%	5.560%
30%	5.470%	11.510%	0.330%	13.080%
40%	11.760%	19.120%	3.320%	21.230%
50%	19.120%	27.020%	9.350%	29.560%
55%	22.990%	31.010%	13.080%	33.760%
Tenure Scheme				
φ	GBM		VAR	
15.5%	2.260%	5.680%	0.170%	7.100%
20%	4.650%	9.290%	0.960%	11.320%
30%	11.950%	18.250%	5.890%	21.440%
40%	20.650%	27.760%	13.880%	31.980%
50%	29.960%	37.470%	23.340%	42.670%
55%	34.740%	42.370%	28.340%	48.060%

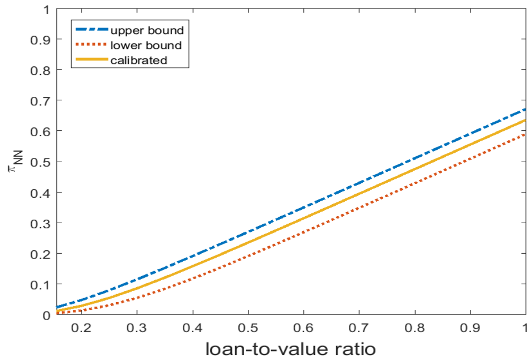
Table 3.8: The boundaries of π_{NN} in the two models. The first column contains the loan-to-value ratios; the second and third columns contain the lower and upper bound of π_{NN} in the GBM model; the fourth and fifth columns contain the lower and upper bound of π_{NN} in the VAR model.



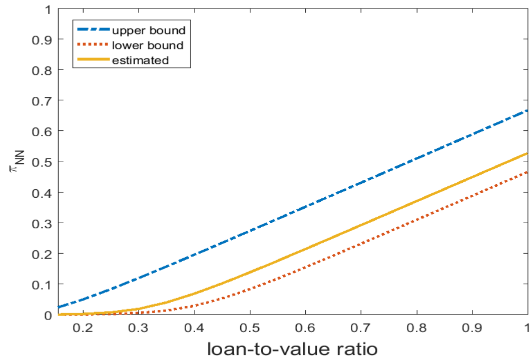
(a) GBM: lump-sum



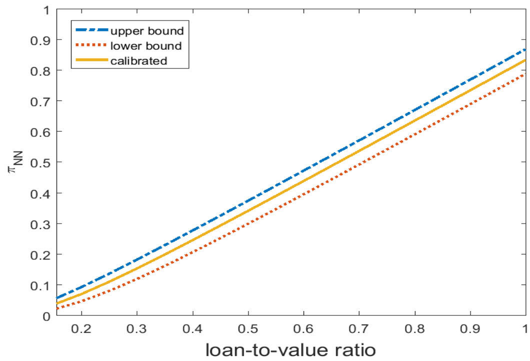
(b) VAR: lump-sum



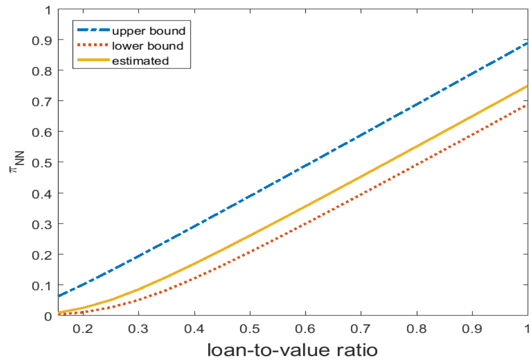
(c) GBM: interest-only



(d) VAR: interest-only



(e) GBM: tenure



(f) VAR: tenure

Figure 3.10: These figures show π_{NN} as a function of the loan-to-value ratio in the three reverse mortgage schemes. Figures on the left panels are from the GBM model, and figures on the right panels are from the VAR model. Lines of different types represent different house dividend rates in the GBM model and different house price growth rates in the VAR model. Dotted lines in the right figures indicate the situation with house price growth rate set to $\mu^{p}_{\text{hpi},min}$, and in the left figures they correspond to the situation with the dividend rate set to q_{max}; dash-dotted lines in the right figures indicate situation with the house price growth rate set to $\mu^{p}_{\text{hpi},max}$ and in the left figures they correspond to the situation with $q = q_{min}$. The solid lines represent the π_{NN} corresponding to the calibrated dividend rate ($q = 5.6\%$) in the GBM model and the estimated house price growth rate ($\mu_{\text{hpi}} = -1.96\%$) in the VAR model.

model are somewhat smaller, but still large, and always included in the intervals of the VAR model. These wide intervals, based on a regular mortgage based calibration, show that there is considerable model risk when pricing the *NNEG* of reverse mortgage products. This might be another reason why the reverse mortgage market is so small. If there is an active housing market, where reverse mortgage providers can use derivatives to reduce the exposure to model risk, the reverse mortgage market might expand.

Table 3.9 shows the maximum allowed loan-to-value ratio by the Dutch mortgage provider Florius for lump sum reverse mortgages, as a function of the age(s) of the buyer(s).[5] For the couple that we consider, the maximum loan-to-value ratio is 15.5%. The reverse mortgage interest rate charged by Florius is fixed at 3.9% regardless of the age and loan-to-value ratio.[6] So, we cannot directly make a comparison with our model based calculations of π_{NN}. Based on a simple "back-of-the-envelope" calculation, assuming that the *NNEG* corresponds more or less to the difference between the reverse mortgage interest rate and a regular thirty-year mortgage interest rate (3.45%, see Table 3.3), we find a value for the *NNEG* around 3.9% which is inside the intervals of both the GBM and VAR models.

Age	65	70	75	80	85	couple (64+67)
$\max\varphi$	18.5%	23.9%	29.6%	35.3%	40.1%	15.5%

Table 3.9: The maximum loan-to-value ratio allowed by Florius

In Figure 3.11 we plot the bounds of π_{NN} corresponding to the cases presented in Table 3.9 based on the GBM and VAR model. Thus, for the 65-year-olds, we use $\varphi = 18.5\%$, for the 70-year-olds we use $\varphi = 23.9\%$, and so on. We also include as reference the simple "back-of-the-envelope" based calculation of the *NNEG* using the reverse mortgage and regular mortgage rates of Florius. Similar to the results for the couples, we find a wide range for π_{NN}, ranging from close to 0% to almost 7% for a 70-year-old to a range from close to 0% to around 3.5% for an 85-year-old. Again the

[5]These data are obtained from the Florius website on 8 April 2016, see `https://www.florius.nl/Pages/handig/bereken-verzilver-hypotheek.aspx`. After we fill in the date of birth and the house value of the buyer, the maximum loan-to-value ratio will be obtained with the existing mortgage on the property equal to zero.

[6]The mortgage rate is also obtained from the Florius website on 8 April 2016, see previous footnote.

interval in case of the GBM model is narrower than in case of the VAR model, but for higher ages the GBM range is no longer fully contained in the VAR range.

In our analysis, we have assumed that the termination rates are mortality rates given by the AG2014 life table. However, there are two opposite forces that may drive the termination rates away from the mortality rates in the AG2014 life table. On the one hand, there might be adverse selection in buying a reverse mortgage product. Those who have a longer subjective life expectancy may be more willing to buy a reverse mortgage product. Thus, the mortality rates might be overestimated. On the other hand, the termination probability may be underestimated because we ignore other reasons for termination, for instance moving permanently to a nursing home. The fact that in our analysis we did not account for adverse selection and have assumed away the possibility of termination due to causes other than decease implies that the degree of model risk in the price of reverse mortgages is likely underestimated. We therefore performed a sensitivity analysis in which we investigate the effects of alternative assumptions regarding the termination rate on the price of reverse mortgages. We look at both cases where termination rates increase and cases where termination rates decrease as compared to mortality rates from AG2014. Chen, et al. (2011) and the HUD assume that the mobility rate is about 30% of the mortality rate. Therefore, as an upper bound we consider the case where the termination rate is 130% of the mortality rate given by the AG2014 table. We also consider cases where the termination rate is 110% or 120% of the mortality rate. To investigate the potential impact of adverse selection, we consider the case where the termination rate is 10%, 20% or 30% lower than the mortality rate according to the AG2014 table. We find that increasing the termination rate reduces the value of the $NNEG$ and the sensitivity of π_{NN} to the main parameters while decreasing the termination rates has the opposite effect. But qualitatively, the results are largely consistent with the findings when using the AG2014 life table. The main difference is that the rates charged by Florius fall below the lower bound of the rates for the GBM model when termination rates decrease by at least 20%. However, this is a quite extreme case. If the mobility rate is 30% of the mortality rate, then a decrease of 20% in the termination rate as compared to AG2014 implies that the adverse selection reduces the mortality rate by 38.5%.

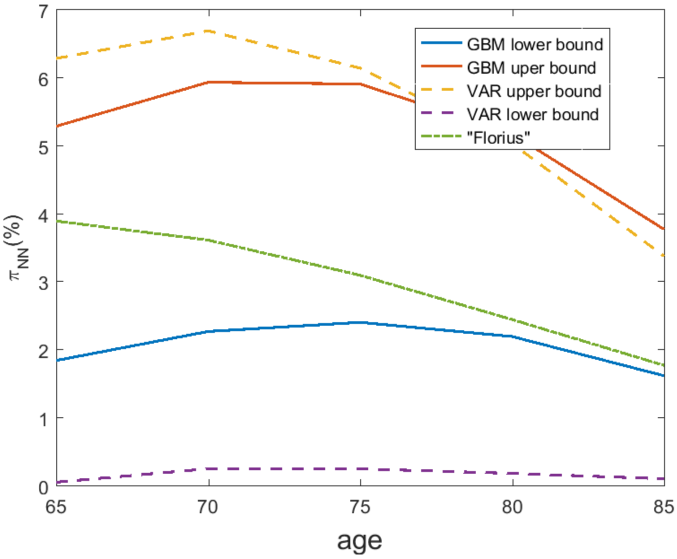


Figure 3.11: This figure displays the model implied *NNEG*. The solid lines represent π_{NN} implied by the GBM model. The dashed lines represent π_{NN} implied by the VAR model. The corresponding loan-to-value ratios are taken from Table 3.9. As reference, the dash-dotted line shows the calculation of π_{NN} assuming that the *NNEG* corresponds to the difference between the reverse mortgage interest rate (3.9%) and a regular thirty-year mortgage interest rate (3.45%, see Table 3.3).

3.7 Conclusion

In this paper, we price the No-Negative-Equity-Guarantee (*NNEG*) of reverse mortgage products using two different models. In the first model, the house price follows a Geometric Brownian Motion. Treating the house as a dividend paying asset, we can price the value of the *NNEG* as a put option with the strike price equal to the loan balance. In the second model, we model the house price and the stochastic discount factor using a Vector Auto Regression (VAR) model. In this way, the house price movement is allowed to be correlated with other macro-economic factors.

Based on our sensitivity analysis, we find that the dividend rate has a substantial impact on the price of the *NNEG*. For example, the partial derivative of the value of *NNEG* to the dividend rate is around 4 at the benchmark in the GBM model. An increasing dividend rate will dramatically increase the value of the *NNEG* and thus decrease the amount of cash that can be released from the house.

We calibrate a range of the dividend yield in the GBM model and of the house price growth rate in the VAR model using regular mortgage data. For the dividend rate we find a range of 4.6% to 6.6%. For the mortgage data based drift μ^m_{hpi} we find a range of -4.99% to -1.14%. Given these calibrated parameter ranges, we determine the model implied price ranges of the price of the *NNEG*. These price ranges turn out to be quite substantial, implying that there is considerable model risk when pricing the *NNEG* using the models that we consider.

This substantial model risk means that pricing the *NNEG* in reverse mortgage products is quite a challenging task. However, in our approach we made a number of possibly restrictive assumptions, which might have impact on our findings. For example, in practice regular and reverse mortgage interest rates might be determined in a different way than we model. This might affect our calibration results, in particular, it might affect the amount of model risk that we find. In the GBM model we only allow for one source of risk. In the VAR model we allow for multiple sources of risk, but, at least in the version that we present, we assume that the house price of idiosyncratic risk is equal to zero. Other ways of calibrating the prices of idiosyncratic risk and the dividend yield might yield different outcomes. When calibrating the ranges of the dividend yield (in the GBM model) and the house price growth rate (in the VAR model), presented in the Appendix, we also impose strong assumptions. For example, we assume independence between the financial risk, house price risk, and default risk. Relaxing these and other assumptions might affect the model risk. Finally, we present results for both the GBM and a version of the VAR model, but without making a clear choice between them. These are topics of future research.

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Appendix

We use ordinary mortgage products to calibrate the dividend rate q in the Geometric Brownian Motion Model and the expected house price growth rate μ_{hpi} in the VAR Model. First, we describe the mortgage products used in the calibration. Next, we discuss the calibration of the two aforementioned parameters in the two models. Table 3.10 summarizes the notation used in the main text and in this appendix.

Mortgage Products—The cash flow pattern associated with a regular mortgage is very straightforward. A cash outflow equal to the initial loan amount is lent to the borrower at the beginning of the contract and in the following years cash inflows will be generated from the interest payments and the repayments of the loans. From the lenders' perspective, risks involved in a normal mortgage are due to the default of the borrowers in combination with a house value lower than the loan balance. To compensate the default risk, the bank charges an interest-rate that is above the market-consistent rate without default. We can use the default probability and the recovery rate in case of a default to assess the present value of the expected cash inflow at the contract initiation, which can be compared to the cash outflow– the initial loan amount. In addition to the default premium, the bank needs to reserve some capital that is at least 4% of the loan balance as required by the Basel 1. The required return on the reserved capital, the hurdle rate, is set to be 9.33%.[7] Besides, we assume there is a 1% operation cost proportional to the loan balance. By setting the net present value of all cash flows to the sum of the present value of the operation cost and required profit on the reserved capital, we can derive the model-implied mortgage rate, which depends on the loan-to-value ratio φ. We then compare the interest rates for loan-to-value ratios $\varphi = 98\%$ and $\varphi = 67\%$ to the market rates, which are displayed in Table 3.3.

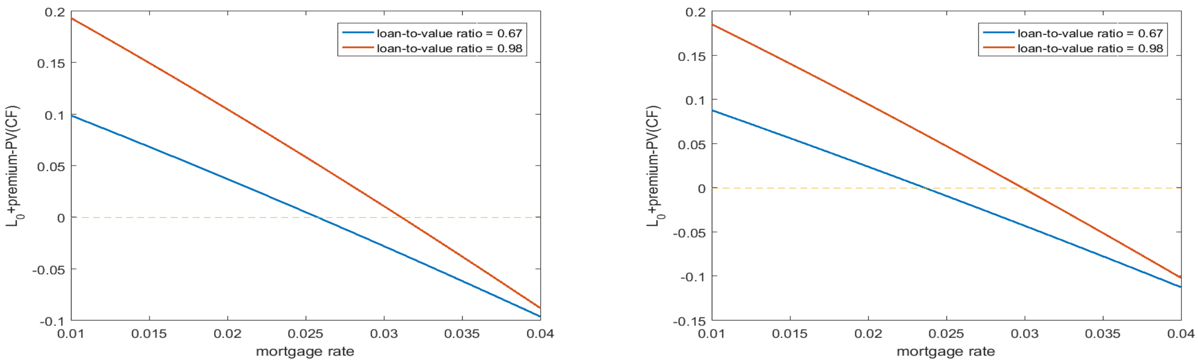
The Geometric Brownian Motion (GBM) Model—The mortgage contract that we consider is an annuity mortgage, which means that the lender pays a fixed amount per year during the entire lifetime of the mortgage. In line with the continuous-time nature of the GBM model, we assume that the lender pays a continuous cash flow at an annual rate denoted by A. In the GBM model, with R denoting the mortgage rate, the remaining liability L_t of the mortgage then satisfies

$$\frac{dL_t}{dt} = RL_t - A,$$

[7] R. Tigchelaar, March 2014, Evaluation of methods for determining the credit risk premium for mortgages.

Variable	Definition
(x, y)	The ages of the two spouses of the household (x: husband; y: wife)
T_x, T_y	The times of death of the two spouses of the household
${}_sp^{(g)}_{z,t}$	The probability that a z-year-old in year t with gender g survives at least s more years
$q^{(g)}_{z,t}$	The probability that a z-year-old in year t with gender g dies within a year
$p_0^{(t)}$	The date-zero price of a zero-coupon bond with a unit payoff in date t
L_t	The value of the loan balance at date t
H_t	The value of the property at date t
φ	The loan-to-value ratio
δ	The proportional transaction cost related to selling the house
T	The time at which the reverse mortgage contract terminates, i.e., $T = \max\{T_x, T_y\}$
T_m	The term to maturity of a regular mortgage
$T_{\max}$	The maximum value of T
m_t	The stochastic discount factor linking year $t-1$ to year t
M_t	The stochastic discount factor linking year 0 to year t
C	The fixed payments made each period in the tenure contracts
NN_T	The value of the *No-Negative-Equity-Guarantee* (*NNEG*) at contract termination
π_{NN}	The premium for the *No-Negative-Equity-Guarantee* (*NNEG*)
$\tilde{\pi}_{NN}(t)$	The premium for the *No-Negative-Equity-Guarantee* (*NNEG*) ending at date t
q	Fixed house net dividend rate
$q_{\min}$	The lower bound of the net dividend rate
$q_{\max}$	The upper bound of the net dividend rate
Φ	The cumulative distribution function of the standard normal distribution
ϕ	The probability distribution function of the standard normal distribution
S	The initial value of the underlying asset
K	Strike price of the put option
r	Reverse mortgage rate
r_f	The risk-free rate in the GBM model
R	Mortgage rate
$R^{Florius}$	Mortgage rate charged by Florius
σ	Annualized house price volatility
κ	Markup for π_{NN}
A	Fixed rate of payments of the regular mortgage
T_m	Term to maturity, $T_m \in \{10, 15, 20\}$
T_f	Horizon for redemption of the loan, which is 30 year
β	The default rate for the mortgage
τ	Time of default
hpi	The house price growth rate
gdp	The GDP growth rate
cpi	The inflation rate
$y^{(1)}$	The 3-month zero-coupon rate
$y^{(40)}$	The 10-year rate
λ	The price of risk
μ^h_{hpi}	The mean of the house price increasing rate estimated using historical house price data
μ^m_{hpi}	The mortgage based drift
$\mu^m_{hpi,min}$	The lower bound of the mortgage based drift
$\mu^m_{hpi,max}$	The lower bound of the mortgage based drift

Table 3.10: This table contains the notations used in this paper.



(a) GBM (b) VAR

Figure 3.12: These graphs plot the difference between the sum of the cash outflow and the required premium (the LHS of equations (3.26) and (3.27)) and the present value of all the future cash flows (the RHS of equations (3.26) and (3.27)) against the interest rate R for mortgage with $T_m = 15$ years. We set the dividend rate q in the GBM model and the house price growth rate μ_{hpi} in the VAR model equal to their calibrated values.

which implies

$$L_t = e^{Rt} L_0 - A\, \frac{e^{Rt} - 1}{R}\,. \tag{3.24}$$

Let T_f be the horizon for redemption of the loan ($T_f = 30$ years). The constant A is chosen such that $L_{T_f} = 0$. In other words,

$$A = \frac{RL_0}{1 - e^{-RT_f}}. \tag{3.25}$$

The value of such a cash flow during the period from 0 to t is:

$$\int_0^t A e^{-r_f t} dt = A \frac{1 - e^{-r_f t}}{r}.$$

The time-to-default is modeled as an exponential distribution, with default rate β set equal to 2% in the calibration. In the calculations, we assume the time-to-default to be independent of (H_t, M_t).[8]

The constant payment should satisfy that the present value of all the future cash

[8]See footnote 1.

flows equals to the initial loan plus the required premium:

$$\begin{aligned}
&L_0 + (\rho + \alpha h) \int_0^{T_m} L_t \exp(-t \cdot r_f) dt \\
=& \int_0^{T_m} \left(A \frac{1 - e^{-r_f t}}{r_f} + \mathbb{E} \left(M_t \min \left\{ L_t, (1-\delta) H_t \right\} \right) \right) \beta e^{-\beta t} dt \\
&+ \left(A \frac{1 - e^{-r_f T_m}}{r_f} + e^{-r_f T_m} L_t \right) e^{-\beta T_m} \\
=& A \frac{1 - e^{-(r_f + \beta) T_m}}{r_f + \beta} + \int_0^{T_m} \mathbb{E} \left(M_t \min \left\{ L_t, (1-\delta) H_t \right\} \right) \beta e^{-\beta t} dt + e^{-r_f T_m} L_t e^{-\beta T_m} \\
=& A \frac{1 - e^{-(r_f + \beta) T_m}}{r_f + \beta} + \int_0^{T_m} e^{-r_f t} L_t \beta e^{-\beta t} dt - \int_0^{T_m} \mathbb{E} \left(M_t \max \left\{ L_t - (1-\delta) H_t, 0 \right\} \right) \\
& \beta e^{-\beta t} dt + e^{-r_f T_m} L_t e^{-\beta T_m} \\
=& A \frac{1 - e^{-(r_f + \beta) T_m}}{r_f + \beta} + \int_0^{T_m} e^{-r_f t} L_t \beta e^{-\beta t} dt - \int_0^{T_m} BSput \left[(1-\delta) H_0, L_t, r_f, q, t, \sigma \right] \\
& \beta e^{-\beta t} dt + e^{-r_f T_m} L_t e^{-\beta T_m}
\end{aligned} \tag{3.26}$$

where $h = 9.33\%$ is the hurdle rate, $\alpha = 4\%$ the reserve rate, and $\rho = 1\%$ the operation cost.

The interest rate R is determined by solving (3.26) using (3.24) and (3.25). Figure 3.12 plots the difference between $L_0 +$ Premium (the LHS of (3.26)) and the present value of all the future cash flows (the RHS of (3.26)) against the interest rate R. The R that leads to an intersection with the horizontal line solves (3.26).

VAR Model—In the VAR model, we adopt a similar approach to calibrate the parameters by fitting the model implied mortgage rate to the observed mortgage rate of Florius. We assume payments occur at the end of every period. The maximum maturity is 30 years. Mortgage with maturity shorter than 30 years needs to refinance at the end of the contract period.

With default risk, the annual payment A is set such that the expected present value of all the future cash flows equal to the initial loan plus the required premium:

$$\begin{aligned}
&L_0 + (\rho + \alpha h) \sum_{t=1}^{T_m} L_{t-1} \mathbb{E} M_t \\
=& \sum_{t=1}^{T_m} \left(\sum_{s=1}^{t-1} \mathbb{E} \left[A \cdot M_s \right] + \mathbb{E} \left[\min\{L_t, (1-\delta) H_t\} M_t \right] \right) \mathbb{P}(\tau = t) \\
&+ \left(\sum_{s=1}^{T_m - 1} \mathbb{E} \left[A \cdot M_s \right] + \mathbb{E} \left[L_{T_m} \cdot M_{T_m} \right] \right) \mathbb{P}(\tau > T_m)
\end{aligned} \tag{3.27}$$

The time-to-default is modeled as a geometric distribution, with default probability β set equal to 2% in the calibration. In the calculations, we assume the time-to-default to be independent of (H_t, M_t).[9] The time-to-default τ is assumed to follow a geometric distribution,

The corresponding interest rate R solves

$$A \cdot \sum_{t=1}^{30} \left(\frac{1}{1+R} \right)^t = L_0, \tag{3.28}$$

and the corresponding loan balance (before period t payment of A) is given by:

$$L_t = L_0 \cdot (1+R)^t - A \cdot \sum_{s=1}^{t-1} (1+R)^s \tag{3.29}$$

for $t > 1$ and $L_1 = L_0 \cdot (1+R)$

The interest rate R follows from solving (3.27), using (3.28) and (3.29). Similar to the GBM model, the R in Figure 3.12 that leads to an intersection with the horizontal line solves (3.27).

[9]See footnote 1.

Chapter 4

The Effect of the New Rural Social Pension Insurance Program on the Retirement and Labor Supply Decision in China

4.1 Introduction

As a developing country that has the world's largest population and a strict family-planning policy, China faces a serious aging problem. By the end of 2014, more than 212.4 million people, i.e., 15.5% of the country's entire population, were aged 60 or over.[1] China differs from most developed countries in that its pension system is rudimentary. Many elderly people, especially those in rural areas, continue to work at a very advanced age.

In 2009, the New Rural Social Pension Insurance program (NRSPI), a voluntary pension program aimed at the rural elderly, was introduced. The program was expanded to nationwide scale in 2012. The amount of basic pension benefits is only 660 CNY per year,[2] which is much lower than the minimum cost of living in rural China. Modest as it is, the NRSPI was the first rural pension program to be strongly promoted by the government and it has reached every village in China. Not surprisingly, the Chinese people want this program to improve the life of the rural elderly. Therefore, it is of interest to find out whether such a modest widely-covered pension program can make a difference for the retirement and old-age labor supply situation in the rural area.

[1] Ministry of Civil Affairs: 2014 Statistical bulletin of Social Service and Development.

[2] 1 US dollar was approximately 6.36 CNY on October 29, 2015.

In this paper, we analyze the effects of the pension provision on the retirement decision using an instrumental variable approach. Receiving pension benefits does not require the pensioners, those enrolled in the pension program and aged 60 and above, to stop working, thus the NRSPI generates a pure income effect for them. The pension contributors, those enrolled in the pension program and younger than 60, nevertheless need to make contributions. The NRSPI helps them to save money for the future. Thus, the effect of NRSPI might be different for contributors and for pensioners. Therefore, we explore the effect of the NRSPI on different kinds of labor supply for both males and females, both pensioners and contributors, to further investigate channels through which the NRSPI affects the labor supply decision.

This paper contributes to the literature in two ways. First, it helps us understand the retirement behavior under a unique social security program. As is argued by Gruber and Wise (2008) in the *Social Security and Retirement Around the World* project, the labor force participation is strongly correlated to the social security programs. Although previous literature shows that pension systems shift people's retirement behavior by providing economic incentives, that literature mainly focused on pension systems providing the main income for the elderly involved. Even the pension system in rural Brazil, another developing country considered in the retirement literature, offers a pension benefit equal to the minimum wage (see de Carvalho Filho (2008)). The benefits from the NRSPI, however, are far below the minimum living cost. This pension program is quite unique and gives us a chance to study whether and, if so, to what extent people respond to such a small amount of money. Besides, the NRSPI is also special since its pension benefits are not contingent on the work status. For those above age 60 when the program was introduced, contribution is not needed at all and they can continue to work while receiving pension benefits; thus, joining the pension program generates a pure income effect.

We also contribute to the literature regarding the impact of non-financial factors by investigating the role played by the regional characteristics in the retirement decision. After controlling for financial situation, demographic background, family structure, etc., there is still a substantial difference in retirement patterns between city dwellers and people living in rural areas.

Our study is an empirical one, with data from a two-wave survey: the China Health and Retirement Longitudinal Study (CHARLS), which covers about 10,000 households and 17,500 individuals aged 45 or older in 150 counties in the years 2011 and 2013. Our empirical results show that after controlling for economic and demographic factors, receiving pension from the NRSPI substantially increases the probability of retirement and decreases the weekly working time for females. The economic value of the changes in the labor supply is far more than the average pension benefits received per year, suggesting that the impact of this pension system goes far beyond the amount of money it brings to the female participants. For male participants, the effect of the NRSPI is not significant. Besides, we further decompose the different kinds of labor supply and find that most of the decrease in labor supply is from agricultural work.

We also examine the segmentation between the urban and rural areas. There are some cultural differences between the urban and rural sides that play a role in people's retirement decision. Population mobility in the rural area is low and people know each other's background, resulting in high peer pressure against deviations from traditional patterns of behavior. Retirement is a relatively new concept, thus less likely to be accepted in the rural area. Although we don't model these differences structurally, our reduced form empirical findings are in favor of this argument. Living in the urban area, *ceteris paribus*, increases the likelihood of retiring at any time during life by 25.7% and 18.3% for females and males, respectively. The decreased weekly working time is 9.7 hours for females and 9.0 hours for males. Most of the observations in our urban sample have an agriculture household registration,[3] indicating that most of them are migrants from the rural area. It seems that after migrating to the urban area, where the concept of retirement is commonly accepted and peer pressure is weaker, their retirement pattern changed and they behave differently from their rural counterparts.

In addition to the above findings, we also find that people tend to work more when they have more never-married sons. One explanation is that, while traditionally adult sons are the main old age support for their old parents, parents do not want to retire before their sons have their own family, since they still need to earn money to increase their sons' bargaining power in the marriage market. This is what is suggested by the theory of Wei and Zhang (2011), namely that people increase saving to improve their relative standing in the marriage market. In the traditional Chinese culture, in addition to the groom's family being responsible for most of the wedding expenditures, they also need to give the bride family the betrothal gift before the wedding. The

[3]We exclude people covered by the urban pension programs. It is very likely that those people have a non-agriculture household registration.

amount of the betrothal gift would signal the wealthiness of the groom's family. The son from a wealthier family is more attractive in the marriage market. The betrothal gift system is economically rational, since traditionally the sons provide the old age support in rural China rather than the daughters.

There is a very recent paper studying the effect of the NRSPI on the labor supply using the CHARLS dataset by Ning et al. (2016). These authors focused on the subsample from the districts that were covered by the NRSPI when the survey was conducted, i.e., 26% of the sample in the first wave and the entire second wave were used to fit a regression-discontinuity model. They found an insignificant effect of the NRSPI on the retirement decision and a significant positive effect of the NRSPI on the labor supply without controlling for the occupation of the individuals. They argued that the increase in the labor supply was caused by a crowding out effect of the NRSPI on the intergenerational economic transfer. One would expect a crowding out transfer larger than the amount of benefits received if the labor supply increases. Yet, none of the three papers (Cheng et al. (2013), Chen and Zeng (2013), Zhang and Chen (2014)) they cited to support the crowding out effect found an effect larger than one. The largest effect is found by Chen and Zeng (2013), which is 62.4%. Zhang and Chen (2014) found that the pension receipts decreased the probability of receiving transfers from the children by 32-56% but had no significant effect on the amount of transfers. Cheng et al. (2013), however, found a positive but insignificant effect of the pension receipts on the intergenerational transfers. In contrast to Ning et al. (2016), we believe the subsample that had no access to the NRSPI in the first wave should also be included in the estimation. It is of particular interest to study the change in the retirement and labor supply behavior of those who had no access to the NRSPI in the first wave but received pension benefits in the second wave. After controlling for the age, the NRSPI still significantly increases the probability of retirement and decreases the labor supply for that group. The results are robust when the squared age is included in the control variables. If we exclude the districts that were not covered by the NRSPI in the first wave, as Ning et al. (2016) did, we also find an insignificant effect of pension receipt on the retirement decision. The effect on the labor supply is also positive but insignificant.

The rest of the paper is organized as follows. Section 4.2 presents previous literature on retirement. In Section 4.3 we discuss the institutional background. The data source and descriptive statistics are presented in Section 4.4. In Section 4.5, we introduce the methodology used in the paper, and Section 4.6 shows the empirical findings. We carry out a sensitivity analysis in Section 4.7 and conclude the paper in Section 4.8.

4.2 Literature

Retirement and old age labor supply attracted great attention in the previous decades. Factors affecting people's retirement decision fall into two categories: financial incentives and non-financial factors. In the neoclassical framework, the retirement decision is part of the life-cycle choice of consumption and leisure. Social security programs, for instance, pension programs, and age related health insurance programs provide financial incentives for people to retire (see, for example, Coile and Gruber (2004); Vere (2011); Stock and Wise (1990); Hurd (1997); Lee (1998)). Individual wealth also plays a role in the retirement decision: wealthier people tend to retire earlier (see Bloemen (2006); Fields and Mitchell (1984)), and decumulation in wealth, like medical expenditure, is important for understanding retirement behavior (see French and Jones (2011)). Non-financial factors include financial literacy (see Van Rooij et al. (2012); Lusardi and Mitchell (2007)), social norms (see Vermeer et al. (2014)), and family obligations (see Szinovacz et al. (2001); Maurer-Fazio et al. (2011)).

However, studies of the retirement decision in developing countries with less sophisticated pension systems are very scarce. Social security in the rural side is sparse, (see Hussain (1994)) and the economic position of the elderly and family as a social security institution seem to be weakened as argued by Benjamin et al. (2000). Pension systems, varying across countries, constitute an important factor of labor market behavior. Based on a pension reform in 1991, de Carvalho Filho (2008) studied the retirement decision of the rural elderly in Brazil and found that receiving old-age pension benefits significantly reduces the probability of working and the number of hours of work.

There are a little number of papers investigating the retirement pattern in China. For example, Benjamin et al. (2003) documented the labor supply situation of the elderly people in China and investigated the effect of age and health on the labor supply of the elderly. Using physical limitations as an instrument for the health situation, and based on three waves of panel data of the China Health and Nutrition Survey (CHNS), they found that health issues can explain half of the reduction in labor supply for men from 60 to 70, but have no significant effect on the labor supply of women. In addition, Giles et al. (2015) documented the retirement patterns and the factors affecting the retirement decisions, based on the first national survey of China Health and Retirement Longitudinal Study (CHARLS).

Zhang et al. (2014) and Chen et al. (2015) analyzed the effect of the NRSPI on work status using a Fuzzy Regression Discontinuity (FRD) model, and Ning et al. (2016) used a combination of Regression Discontinuity and Different-in-Difference. Our paper differs from these three papers in the following ways. Firstly, the first two papers use a cross-sectional data set and the third paper pools the two-wave data together in the estimation, while we use a panel data. With panel data, individual effect is better controlled. Secondly, the sample selection is different. Because the cited papers use a FRD model, only communities which already have access to the pension program can be used. Therefore, only 26% of the whole sample in the first wave are used. In addition to this, an FRD model limits the focus of the mentioned studies to people around the cutoff age; consequently, a local treatment effect is estimated. Our model allows us to investigate a wider sample and a wider age group. This is relevant because the pension contributors' retirement decision also responds to the NRSPI status. Thirdly, an FRD model cannot estimate the effect of the amount of pension benefits on the retirement behavior, while our model is able to do that. Finally, we distinguish between females and males and decompose the total labor supply to further investigate the channel via which the NRSPI plays a role.

In addition to the reduced-form models, there are a few other types of methods that are used in the estimation. Stock and Wise (1990) treated retirement as an option. People reassess the value of continuing to work and immediate retirement every period to make their retirement decision. As long as the value of continuing working is larger, people will not withdraw their labor supply. Samwick (1998) extended the previous study by introducing dis-utility of labor into the model and by extending the dataset from a specific firm to the whole nation. People will stop working when the financial gain from postponing retirement falls just below the utility loss from decreasing leisure.

Another method, heavily used by many researchers, is the life-cycle dynamic programming approach. People maximize their life-cycle utility subject to a budget constraint. Early models like the one used by Gustman and Steinmeier (1985) only considered consumption and the labor supply decision (full-time work, part-time work, and retirement). Later models introduced, for example, wage uncertainty (see Gourinchas and Parker (2002)), health uncertainty and health insurance (see French and Jones (2011)), and saving (see van der Klaauw and Wolpin (2008)).

While structural retirement models allow us to understand the underlying mechanism of the retirement behavior, the drawbacks of this kind of models are also obvious. The estimation is more complex and the results rely heavily on the assumptions. At this stage, we focus on reduced-form models to measure the relation between the NRSPI and the retirement decision in quantitative terms. In further studies, structural estimation could be adopted in order to allow for counterfactual analysis.

4.3 The Institutional Background

The New Rural Social Pension Insurance program (NRSPI) was introduced in 2009, when 320 out of 2 858 counties joined the program as a pilot. In 2010, 518 new counties entered (see Cheng et al. (2015)) followed by 1076 counties in 2011.[4] By the end of 2012, this pension program extended to nationwide scale.

The New Rural Social Pension Insurance program is voluntary for people registered in the rural area and aged 16 or older. However, students and those participating in any other pension plans are excluded. Other pension plans include the government pension program, which is for people working in the government and government institutions, the firm basic pension, which is for firm-employed, and urban residents pension, which is for unemployed people with urban registration. The registration system (*Hukou*) was established in the 1950s to control the population mobility. All individuals are classified into one of two categories: agriculture *Hukou* (rural registration) and non-agriculture *Hukou* (urban registration). A status change from rural to urban registration is very difficult. Therefore, many migrant workers still carry a rural registration even though they are working in the urban area; thus, they still have access to the NRSPI as long as they are not covered by other pension plans.

The pension contributions are shared by individual participants, the local village communities, and the local and central governments. Five basic levels of contribution can be chosen by individual participants, varying from 100 CNY to 500 CNY per year. However, in 10 provinces, another five levels up to 1000 are also available.[5] Nevertheless, the most popular level of contribution is 100 CNY per year (see Lei et al. (2013)). The collective subsidy from the local village is encouraged but not mandatory. Subsidies from the governments are partially matched to the individual contribution level, with a minimum subsidy equal to 30 CNY per year per participant.

[4] Ministry of Human Resources and Social Security of the PRC: `http://www.mohrss.gov.cn/SYrlzyhshbzb/dongtaixinwen/dfdt/gzdt/201201/t20120119_94512.html`.

[5] Ministry of Human Resources and Social Security of the PRC.

The pension benefits consist of the benefits from the individual account and the basic benefits from the government. The individual account is like a DC system, and the basic benefits from the government are similar to the state pension. The monthly amount from the individual account, a life annuity, consists of the accumulated assets in the individual account divided by 139, where 139 is assumed to be the average remaining life expectancy measured in months. The amount of basic benefits from the government is 660 CNY per year. For the east provinces, the central government bears half of the basic benefits, while for the relatively poor middle and west provinces, the central government finances the whole basic benefits.[6]

The minimum age to be qualified to receive the pension benefits is 60. Receiving pension benefits is not contingent on retirement. However, unlike the state pension in most countries, the basic pension benefits are not for everyone above 60 but only for participants. People aged 60 or older before the introduction of the pension program can receive the basic pension benefits without any contribution, but under the condition that their children, if eligible for the program, participate in the program. For those younger than 45 years when the program was introduced, a minimum of 15 years of contribution is needed for entitlement to pension benefits after reaching age 60. There is no minimum number of years of contribution required for those between age 45 and 60.

Compared to the rural poverty line, which was set to be 2 300 CNY per year in 2011[7], the level of pension benefits from the NRSPI is quite low. The basic pension benefits amount to 660 CNY and the level of overall pension benefits in the sample is around 965 CNY, less than half of the rural poverty line. In 2012, the average per person annual net income and consumption in the rural area were 7 916.6 and 5 908 CNY,[8] respectively. Even for families with income in the lowest income group (the bottom 20% quantile), the average per person annual net income and consumption were 2 316.2 and 3 742.4 CNY per year.[9] The pension benefits from the new rural pension program are not sufficient for elderly people to maintain a normal life, but are an important source of income for the lowest income group.

[6]Eight Provinces increased the basic pension. The basic pension of Beijing is 3 960 CNY, Shanghai is 3600 CNY, Tianjin is 1800 CNY, Chongqing is 960 CNY. Other provinces provide amounts varying from 720 to 840 CNY per year. `http://www.mohrss.gov.cn/ncshbxs/NCSHBXSgongzuodongtai/201201/t20120109_83895.htm`.

[7]Data source: National Bureau of Statistics of China.

[8]Data source: National Bureau of Statistics of China.

[9]Data source: National Bureau of Statistics of China.

4.4 Construction and Description of the Main Variables

4.4.1 Data Source

The source of all the data used in this paper is the biennial survey of the China Health and Retirement Longitude Study (CHARLS), with exception of the province level federal revenue, which has been retrieved from the National Bureau of Statistics of China. CHARLS is a nation-wide survey covering approximately 10 000 households, consisting of 17 500 individuals aged 45 or older in 150 counties in the years 2011 and 2013. Following the experience of the Health and Retirement survey (HRS) in the U.S. and the Survey of Health, Aging, and Retirement in Europe (SHARE), it contains information on demographics, family transfers, health status and health care, income and consumption, work, retirement and pension, assets and liabilities, and so on. A detailed description of this study and the advantages of the data set can be found in Lei et al. (2012), Lei et al. (2014), Shen (2014), and Smith et al. (2014).

In this paper, we focus on the retirement decision and old-age labor supply of the elderly. Among the different modules in the questionnaire, we are particularly interested in the work, retirement, and pension parts, taking the demographic information, financial situation, and health conditions as control variables. The construction of the main variables is described in the following section.

4.4.2 Construction of the Variables

Dependent variables

Retirement status: The retirement status R_{it} is a dummy variable that takes the value 1 if individual i is "retired", i.e., not working and not searching for jobs at time t, otherwise it is 0. In the urban side, although compulsory retirement ages are set for workers (65 for males, 60 for white collar females and 55 for blue collar females), there is a mismatch between the retirement procedures and the actual labor supply. According to the survey data, around 35% of the people who have completed the retirement procedure continue to work. Thus, the compulsory retirement ages are not perfect proxies for people's retirement status. In the rural area, many people are engaged in agricultural work and seasonality is the nature of that kind of work. Thus, we define retirement in the following way: if individual i did not engage in any agricultural work for more than 10 days in the previous year, did not work for at least

1 hour in the previous week, is not currently laid-off, and did not search for a new job in the past month, then we consider individual i as retired.

Non-agriculture work status: The non-agricultural work status takes the value 1 if individual i engaged in activities to earn a wage, ran a business or worked for unpaid family business for at least 1 hour in the previous week.

Agriculture work status: The agricultural work status takes the value 1 if individual i engaged in any agriculture work for more than 10 days in the previous year.

Agriculture work status for their own household: The agricultural work status takes the value 1 if individual i worked on their own field for more than 10 days in the previous year.

Weekly working hours: The number of weekly working hours H_{it} is a continuous variable representing the labor supply condition of individual i at time t. As indicated before, agricultural work is seasonal, thus the weekly working hours on agricultural work are rescaled by the number of working months. In the questionnaire, three questions are asked to the farm-employed and those who work on their own household field. *a: How many months did you work on cropping (forestry), livestock, and fishing in the past year? b: How many days did you work per week on average during a normal work month in the past year? c: How many hours did you usually work per day during a normal work day in the past year?* The number of weekly working hours on agricultural work is the product of the answers in these three questions divided by 12. For employed or self-employed work, although the number of months worked is asked as well, survey participants are asked the average working days in a week in the past year and the average working hours per day in the past year. Thus, the number of weekly working hours is just the product of the answers in the last two questions. The total number of weekly working hours is the sum of the weekly working hours for the farm-employed work, work on their own household field, and the non-agricultural work. We also use the three components as dependent variables to investigate more deeply the effect of NRSPI on different kinds of work.

Main explanatory variables

Pension: The pension status $Pension_{it}$ is a dummy variable indicating whether individual i receives pension from the NRSPI at wave t. This variable is used in model 4.1 in section 4.5.

Enrollment: the NRSPI enrollment status $Enroll_{it}$ is a dummy variable as well. If individual i participates in the NRSPI at wave t, it takes the value 1, otherwise it is 0. So, $Enroll_{it} = 1$ for both pension contributors and pensioners. This variable is used in model 4.2.

Pension benefits: the pension benefits $Benefits_{it}$ is the amount of money individual i receives from the New Rural Social Pension Insurance at time t. It is also used in model 4.1.

Main control variables

The control variables include self-reported health status, demographic background, family structure, occupation, financial situation, whether the respondents have grandchildren or old parents to take care of, and district and wave dummies. Self-reported health status varies from 0 (very poor) to 5 (excellent). 49.48% of the sample report their health status as "fair". Education levels are classified into 12 categories, varying from 1 (illiterate) to 12 (doctoral degree). The intermediate levels include not having finished primary school, home school, elementary school, middle school, high school, vocational school, two-/three-year college/associate degree, bachelor, and master degree. Most of the people in the survey have education not higher than elementary school.

4.4.3 Descriptive Statistics of the Samples

The samples are selected by sequentially deleting the observations of individuals that do not satisfy the following criteria. (1) Individuals appear in both surveys, (2) are older than 45, (3) have ever worked in their whole life, (4) are not covered by commercial pension and other urban pension programs in any wave, (5) have full information on the key variables. Before sample selection, we have 36 330 individual-year observations; 5 948, 177, 104, and 8 652 observations drop out because of criteria (1), (2), (3), and (4), respectively. After the selection, we dropped those only appearing in one wave. In the end we have 11 300 observations in the rural group and 1 056 observations in the urban group. Since the New Rural Social Pension Insurance program is for rural-registered people, we first focus on people in the rural area without any other pension other than the NRSPI. However, migrant workers, i.e., those who are rural registered but work and live in the urban area, are also eligible to participate in the NRSPI. To investigate further whether the NRSPI has effects when people move to the urban side, in the next stage we also include people in the urban area in the analysis.

Figures 4.1, 4.2, and 4.3 show the retirement ratio, i.e., the proportion of retired people, as a function of age for different subsamples. Both the rural and urban observations are included in the plots. Figure 4.1 plots the retirement ratio against age by pension status and wave, Figure 4.2 shows the retirement ratio by region and wave, and Figure 4.3 shows the retirement ratio for different genders and waves. We see that the retirement ratio is increasing with age in all three figures. The variable we are interested in, the pension enrollment, does not seem to make a big difference, at least not without controlling for other variables. From Figure 4.1, we cannot see a substantial difference in terms of the retirement ratio for those participate in the NRSPI, the pension participants, and those who do not participate in the NRSPI, the non-participants. Differences between people in the urban and rural areas (Figure 4.2) and between different genders (Figure 4.3) are quite substantial. As shown in Figure 4.2, at the age of 60, around 40% of the people in the urban area are retired, but only 10% are retired in the rural area. Even after age 70, most of the rural residents still work. In terms of gender differences, the retirement ratio of women is higher than that of men. As stated before, the retirement age for males is 60, for white collar females is 55, and 50 for blue collar females. However, there is no substantial jump at those ages because the fraction of people working in the government and firms, where the retirement regulation is applied, is very low and many of them continue to work after the compulsory retirement ages.

Figures 4.4, 4.5, and 4.6 present the average weekly working hours as a function of age for different subsamples. Both the rural and urban observations are included in the figure plots. Figure 4.4 presents the average working hours against age for people with different pension status, Figure 4.5 is grouped by region, and 4.6 is grouped by gender. Again, without controlling for other variables, there is no substantial difference in working hours between pension participants and non-participants. The difference in working hours between the urban and rural areas is not substantial, especially before age 50. However, urban people between age 60 and 65 on average work less than their rural counterparties. For people at very advanced age, the difference is diminishing. But as the number of observations for elderly people in the urban side is small, those differences may be driven by disturbances. Figure 4.6 shows that males typically work longer than females.

Figure 4.7 shows the proportion of people who receive pension benefits from the NRSPI in the rural area. Those enrolled in the other pension programs are excluded. People begin to receive pension at the age 60 if they are enrolled in the NRSPI.

Thus, we see a big jump at the age of 60 and 61. The reason that there is a jump at 61 is because some people use the nominal age[10] which is usually 1 year older than the actual age. From Figure 4.8, we see that the pension program expanded quickly between the two waves. In 2011, about 20-30% of the rural villagers were covered in the program. In 2013, the coverage ratio increased to about 80%.

The means and numbers of observations of the main variables are summarized in Table 4.1. In column (1), we present the sample average for females, column (2) is for males, and column (3) covers the whole sample. Consistent with Figures 4.3 and 4.6, females are more likely to get retired, and work less. The average difference in weekly working hours between males and females is around 10 hours. Moreover, the allocation of time to different kinds of work is different, too. Males spend twice as much time on non-agriculture work as females do, but the differences with respect to agricultural work are small. These findings motivate us to investigate the effect of NRSPI for males and females separately.

The average level of total pension income from the New Rural Social Pension Insurance program is around 857 CNY per year. It is quite small when compared to the household income, which amounts to around 13 170 CNY per year.

4.5 Model

From the descriptive statistics in section 4.4, we cannot see the impact of the NRSPI on the retirement and labor supply situation. In this section, we use econometric models to analyze the impact of the pension income by estimating the following regression equation:

$$y_{it} = \alpha + Pension_{it}\gamma + Pension_{it} \times Benefits_{it}\theta + X'_{it}\beta + D'_i\delta + Wave_t\psi + \alpha_i + \varepsilon_{it} \quad (4.1)$$

which can be estimated using G2SLS with the first-stage:

$$\begin{aligned} Pension_{it} &= a_0 + Z_{it}a_1 + X'_{-it}a_2 + D'_i a_3 + Wave_t a_4 + \eta_{1,i} + \nu_{1,it}, \\ Pension_{it} \times Benefits_{it} &= b_0 + Z_{it}b_1 + X'_{-it}b_2 + D'_i b_3 + Wave_t b_4 + \eta_{2,i} + \nu_{2,it}, \\ Health_{it} &= c_0 + Z_{it}c_1 + X'_{-it}c_2 + D'_i c_3 + Wave_t c_4 + \eta_{3,i} + \nu_{3,it}, \end{aligned}$$

where

[10]Newborns start at age of 1 instead of age 0. See Wikipedia *East Asian age reckoning*: `https://en.wikipedia.org/wiki/East_Asian_age_reckoning`.

y_{it} is the dependent variable that can be the retirement status R_{it}, the hours of the weekly labor supply H_{it}, or the work status and weekly working hours of different kinds of work as discussed in section 4.4.2. Detailed description of the variables is given in section 4.4.2;

$Pension_{it}$ is a dummy variable indicating whether individual i receives pension benefits at time t;

$Benefits_{it}$ is the amount of the received benefits;

$Health_{it}$ is the subjective health status;

X_{it} refers to other individual background characteristics, including occupation type, education level, marital status, age, self-reported health status, financial situation, taking care of elderly parents or young grandchildren, and family structure;

X_{-it} the control variables excluding the self-reported health status;

Z_{it} the instrumental variables described later;

D_i represents district dummies referring to Eastern China, Middle China, Western China, and Northeastern China. Middle China is set as the benchmark;

$Wave_t$ is the wave dummy with the first wave equal to 0 and the second wave equal to 1;

α, γ, θ, β, δ, ψ, a_0 to a_4, b_0 to b_4, and c_0 to c_4 are vectors of parameters to be estimated;

α_i and $\eta_{n,i}, n \in (1,2,3)$ are the individual effects with $\alpha_i \sim (\mu_{\alpha_i}, \sigma^2_{\alpha,i})$, $\eta_{n,i} \sim (0, \sigma^2_{\eta,n,i})$;

ε_{it} and $\nu_{n,it}, n \in (1,2,3)$ are the error terms with $\varepsilon_{it} \sim (\mu_\varepsilon, \sigma^2_{\varepsilon,i})$, $\nu_{n,it} \sim (0, \sigma^2_{\nu,n,i})$.

As discussed in section 4.3, the NRSPI is voluntary and the pension benefits can be determined to some extent by the pension participants. Villagers younger than 60 years when the program was introduced can choose the level of contribution, which will affect the pension benefits they are about to receive after age 60. People who want to retire may have more incentive to join the NRSPI and choose a higher level of contribution. It is therefore very likely that the NRSPI enrollment status and the pension benefits are correlated with the error term ε_{it}. So, the assumption of exogeneity of the independent variables may lead to biased estimation results. Previous literature deals with this problem by utilizing discontinuity regression, see Chen (2015), or an instrumental variable approach, see Cheng et al. (2015), de Carvalho Filho (2008), and Vere (2011). The existence of the endogeneity problem also makes the linear probability model attractive in the estimation of retirement status.

We adopt an instrumental variable approach to deal with the endogeneity problem. We assume the instrument variables are exogenous but are correlated with the endogenous variables. Following Cheng et al. (2015), we choose the first instrumental variable as the length of the duration of the pension program in each community. The pension program was launched at different times for different communities, therefore, the pension status will be correlated to the duration of the pension program. The longer the duration, the more likely people are enrolled in the NRSPI. The implementation of the pension program was determined by the government, and thus the assumption of zero correlation with the retirement and labor supply situation of the individual villagers seems plausible. For each community, we define the duration of the New Rural Social Pension Insurance program as the difference between the survey time and the time the first villager in the community joined the pension program. For communities without any pensioner, we set the duration equal to zero.

The second instrumental variable is the province level federal revenue. Both the basic pension and government subsidies can vary across provinces and their level may be related to the federal revenue, since the local government can adjust the basic pension and subsidies based on its economic situation. This not only directly affects the pension benefits, but also influences the pension enrollment decision, since people are more incentivized to participate when the compensation is higher. Since the province level federal revenue is not determined by individuals, it is expected to be independent of the error terms.

A second endogeneity problem arises with the use of the self-reported health status. There is a large literature documenting the effect of health on labor supply and retirement, in which the measurement of the health condition is highlighted. In addition to the self-reported health condition, more objective measures of health condition were adopted, for instance, the constructed "health stock" (see Hagan et al. (2008), Disney et al. (2006), and Bound et al. (1999)), which uses the presence of specific conditions and activity limitations to instrument the self-assessed health condition (see Stern (1989)). As indicated by Jones et al. (see Jones et al. (2010)), constructing the health stock using objective measures is analogous to using more objective health indicators as instrumental variables for self-reported health condition. Besides, Dwyer and Mitchell (1999) found that neither the self-reported health condition nor the objective health indicators are endogenous when they compare the results to the one using hospital stay situation and parental health and mortality as instruments. Moreover, self-reported health condition is important in explaining retirement because other objective health indicators measure health condition rather than work capacity (see Bound (1991)). Thus, in this paper, we follow the previous literature and use objective health indicators as instruments for self-reported health condition. The health indicators include the presence of certain diseases and physical limitations.

After the analysis of the effects of receiving pension from the New Rural Social Pension Insurance program, we want to investigate the effects of pension enrollment on pension contributors' retirement and labor supply situation. The pension contributors are people making pension contributions, whose ages are below 60, and who are therefore not eligible to receive pension benefits. The model used in this estimation is

$$y_{it} = A + Enroll_{it}\Gamma + X'_{it}B + D_i\Delta + Wave_t\Psi + A_i + \Upsilon_{it}. \tag{4.2}$$

Similarly, this model is estimated using G2SLS with the first stage

$$\begin{aligned} Enroll_{it} &= A_0 + Z_{it}A_1 + X'_{-it}A_2 + D'_iA_3 + Wave_tA_4 + H_{1,i} + \Omega_{1,it}, \\ Health_{it} &= C_0 + Z_{it}C_1 + X'_{-it}C_2 + D'_iC_3 + Wave_tC_4 + H_{3,i} + \Omega_{3,it}, \end{aligned}$$

where

$Enroll_{it}$ is the pension enrollment status, whether individual i is enrolled in the NRSPI at time t;

Γ, A, B, Δ, Ψ, A_0 to A_4, and C_0 to C_4 are vectors of parameters to be estimated;

A_i and $H_{n,i}, n \in (1,3)$ are the individual effects with $A_i \sim (\mu_{A_i}, \sigma^2_{A,i})$, and $H_{n,i} \sim (0, \sigma^2_{H,n,i})$;

Υ_{it} and $\Omega_{n,it}, n \in (1,3)$ are the error terms with $\Upsilon_{it} \sim (\mu_\Upsilon, \sigma^2_{\Upsilon,i})$, and $\Omega_{n,i} \sim (0, \sigma^2_{\Omega,n,i})$;

y_{it}, X_{it}, X_{-it}, Z_{iT}, D_i and $Wave_t$ refer to the same variables as in model 4.1.

4.6 Empirical Results

4.6.1 The Effect on the Pensioners

As discussed in section 4.4, the labor supply situations and the retirement statuses of females and males are quite different. A formal test of equality of the regression coefficients also shows that the regression coefficients for the two groups are significantly different at the 5% significance level. Therefore, in this section, we analyze the effect of the New Rural Social Pension Insurance program separately for different genders.

We first look at the effect of receiving pension benefits on the retirement status of males and females in the rural side. Model 4.1 is used in the estimation and the results are presented in Table 4.2. In columns (1) to (3), the dependent variable is the retirement status. Column (1) contains the results when both males and females are included in the sample. Columns (2) and (3) contain the results when males and females are estimated separately. The coefficients of $Pension_{it}$ and $Pension_{it} \times Benefits_{it}$ are significantly different from 0 in column (3), showing that receiving pension benefits can substantially change the retirement status of females. However, for males, the effect is not significant as shown in column (2). For most of the sample, the partial effect of pension receipt, $\partial E(y)/\partial(Pension)$, on female is around 10% as shown in Figure 4.9.

Columns (4) to (6) of Table 4.2 present the effect of receiving pension benefits on labor supply for the whole sample, the males, and the females, respectively. The dependent variables are the weekly working hours. We fit model 4.1 to the rural observations in this estimation as well. In the whole sample with both males and females, the partial effect of receiving pension benefits on labor supply is around 17 hours. We plot the partial effect in Figure 4.9. The horizontal axis represents the fraction of the data, and the vertical axis represents the partial effect. In 80% of the sample, the deduction in labor supply falls in the range of 15-20 hours. For males, the coefficients on the variable $Pension_{it}$ and the interaction term are not significantly different from 0, indicating that the effect of the NRSPI on labor supply of males is not significant. But for females, receiving pension benefits decreases the labor supply substantially. Compared to males, females have a lower productivity on agricultural work; the pension benefits are worth more work for them.

We further decompose the total labor supply into non-agricultural labor supply and agricultural labor supply in Table 4.3. The dependent variables are the weekly working hours of non-agricultural work for the first three columns, the weekly working hours of agricultural work for columns (4) to (6), and the weekly working hours on one's own household fields for columns (7) to (9). The coefficients on the main explanatory variables are insignificant in columns (2) and (3), indicating neither females nor males substantially change their non-agricultural labor supply after receiving pension benefits. But they all decrease their agricultural labor supply accordingly, and females respond more to the pension program, as shown in columns (5) and (6). Most of the decrease in agricultural labor supply comes from decreased working hours on the participants' own fields. This finding is reasonable given that rural people allocate most of their working time to household agricultural work. Remarkably, however, the amount of decreased labor supply for females is very large when comparing it to the amount of benefits received. As shown in Table 4.1, the average annual benefits received by females amount to only 860 CNY. This is about the wage of 78 hours of work if we use the minimum wage of 11.73 CNY.[11] Two reasons might explain this phenomenon. In the rural side, the actual economic value of one hour's work might be far below the minimum wage. Farmers can spend lots of time on the field but the production cannot be raised proportionally. Besides, for older workers, working on the field might be a very heavy burden and the disutility of labor is very high.

The big effect of the NRSPI found in this paper is in line with previous findings. According to the analysis of Chen et al. (2015), the probability of retirement increased by 13.2% to 36.8% based on different model specifications. The size of the effect as estimated by Zhang et al. (2014) is around 25%. One possible explanation of the big impact of the NRSPI is that the introduction of this pension program brings rural people a feeling that the government is taking care of them so that they can have the opportunity to retire. The findings in Table 4.4 (the effect of the amount of received pension on the work/retirement status) and Table 4.5 (the effect of the amount of received pension on the labor supply) confirm this explanation. The dependent variables in Table 4.4 are the retirement status in the top panel of the first three columns, the agricultural work status in the bottom panel of the first three columns, the non-agricultural work status in the top panel of the last three columns, and the agricultural work status on their own household field in the bottom panel of the last three columns. Only the coefficients on pension benefits, health status, gender, and number of never married sons are presented in the table.[12] The dependent variables in Table 4.5 are the total weekly working hours, the weekly working hours on agricultural work, non-agricultural work, and own household field agricultural work from the top left panel to the bottom right panel. None of the coefficients on pension benefits are significant in these two tables. When we focus on the subsample of pension receivers, the amount of pension benefits has no significant effect on the retirement decision or the labor supply situation. It seems people are motivated mostly by whether they get something, rather than by how much they get. Traditionally, people in the rural area did not have the concept of retirement. This pension program can also spread the concept of retirement among pension contributors and pensioners. Although the above explanations are in line with our findings, they cannot be verified using the

[11] In 2014, the average minimum hourly wage in China was 11.73 CNY. See website: http://www.china-briefing.com/news/2014/06/11/complete-guide-minimum-wage-levels-across-china-2014.html.

[12] The full table is available upon request.

reduced-form regression analysis. Further structural estimation is needed to reveal the reason why the NRSPI has such a sizable effect. Anyway, the NRSPI is the first pension program that covers the whole rural area. Its sizable effect is found not only on the labor supply decision, but also on people's living arrangement (Chen (2015), and Cheng et al. (2015)) and health (Cheng et al. (2016)).

In contrast to our findings, as discussed in the introduction, Ning et al. (2016) found an insignificant effect of the NRSPI on the labor supply. The sample size in their study is much smaller since they only include districts where the NRSPI was introduced at the survey time, which means 74% of the samples in the first wave are excluded. Moreover, they use a different definition of retirement. People working less than 52 hours are considered as retired in their study. Thus the annual working hours need to be measured to determine the retirement status. At the left tail of the annual working hours, the value of the retirement status might be very sensitive to the choice of the cutoff. Besides, such a definition might wrongly classify people currently laid off to be "retired". In addition, their model has less control variables, for instance the occupation, which we believe strongly affects people's retirement decision.

Another interesting finding is the role the number of never married sons is playing in people's retirement and labor supply decision. Although adult children, especially adult sons, are very important old age supporters, people need to work more before their single sons are getting married. The coefficients on the number of never married sons are significantly larger than 0 for males in column (5) of Table 4.2, columns (5) and (8) of Table 4.3, where the dependent variables are the weekly working hours, the weekly agricultural working hours, and the weekly agricultural working hours on one's own household field, respectively. This is in line with the competitive saving theory proposed by Wei and Zhang (2011). People with single sons need to work harder to improve their son's relative attractiveness for marriage.

Consistent with the previous literature (see Benjamin et al. (2003)), health conditions play an important role in people's retirement decision. People with poorer health are more likely to get retired, and to work less. The coefficient of health is always significantly less than 0 when the dependent variable is the retirement status and significantly larger than 0 when the dependent variable is the weekly working hours as shown in the columns in Tables 4.2 and 4.3. Occupation affects the retirement planning as well. People engaged in agricultural work are less likely to retire, and work for more hours per week, which can be shown by the coefficients of farming in Table 4.2.

4.6.2 The Effect on the Pension Contributors

According to the regulation framework, only pension participants above the age of 60 can receive pension benefits from the NRSPI. Our sample includes a group of people below age 60. For them, enrolling in the New Rural Social Pension program means that they need to make contributions. They haven't received any pension benefits from the pension program. We want to see how the pension program will affect the pension contributors' labor supply decision, whether they will work more to earn money to make contributions. Since there are no received pension benefits, the model used in this subsection is model 4.2.

Table 4.6 shows the effect of pension enrollment on the retirement status for the pension contributors. In the first three columns, the dependent variable is the retirement status, in the last three columns it is the non-agricultural work status. The coefficients of pension enrollment on the retirement status are only significant for the female group in column (3). It suggests female contributors will increase the probability of retirement by around 16.6% after enrolling in the pension program. As for agricultural work, Table 4.7 shows females will decrease the working probability by 13.9% (column (3) of Table 4.7) but the effect of pension enrollment on males is not significantly different from 0. Again, the decrease in agricultural work is mainly driven by decrease of own-field labor supply as shown in column (6).

The labor supply situations of female contributors and male contributors are shown in Table 4.8. The dependent variables for the first three and last three columns are the weekly working hours, and the weekly non-agricultural working hours, respectively. Similar to the retirement status, instead of working more, female contributors will significantly decrease their weekly labor supply by 12.4 hours. The agricultural labor supplies of both females and males are affected as shown in the first three columns of Table 4.9. The difference is that the influence on female contributors is more significant and more sizable. Columns (4) to (6) of Table 4.9 show the effect of pension enrollment on the weekly working hours on one's own household field. Similar as before, only females will decrease their labor supply after pension enrollment.

Although the NRSPI generates a cash outflow for pension contributors, female contributors still decrease their labor supply and increase the likelihood of retirement. It is possible that within a household, the younger contributors and male contributors work to pay the pension contribution while the female contributors work less. The finding that instead of working more, female contributors work less also supports our previous explanation that the feeling to be taken care of after joining the

NRSPI matters in the labor supply decision. However, to verify those explanations, a structural model is needed, which is beyond the scope of this paper.

4.7 Sensitivity Analysis

In this section, we look at how robust the results are to changes in the sample and in the model specification. We first extend our sample to include migrants in the urban side. Next, we compare the linear probability model and the Probit model estimation results. Then we adopt a Fuzzy Regression Discontinuity (FRD) model to analyze further how robust the results are to different model settings and compare our findings with the findings in the previous literature.

4.7.1 Extended Sample Size

We further include people in the urban area but not covered by other pension programs, to see whether the NRSPI affects those in the urban side. As mentioned before, there are many migrants from the rural side who work in the urban side. Thus, even in the urban side, there are people enrolled in the NRSPI. To analyze the effect of the NRSPI on their retirement and labor supply decision, model 4.1 is being used in this subsection.

Tables 4.10, 4.11, 4.12, and 4.13 present the results for the extended sample. The columns with header "All" contain results for the sample with both males and females, the columns with header "Male" contain results for the male subsample, and the columns with header "Female" contain results for the female subsample. The dependent variables are the headers below the column label. Similarly as before, enrolling in the NRSPI increases the likelihood to retire (column (3) of Tables 4.10) and decreases the number of working hours per week (column (3) of Table 4.12) for females. Retiring from work (column (6) of Table 4.11) and decreased labor supply (column (6) of Table 4.13) are mainly from own-field agricultural work as well. However, the magnitudes of the coefficient estimators are smaller. The pension program has less effect on people living in the urban area.

Previous studies, for instance, Sicular et al. (2007) investigate the income difference and inequality between the rural and the urban areas in China. As shown in this paper (see their tables 10 and 12), there are substantial differences in terms of retirement status, and working hours between the urban and the rural area. After controlling for demographic background, social welfare, financial situation, gender, and family situation, people in the urban area are still more likely to go into retirement and to work for less hours than their rural counterparts. This suggests retirement is not only an economic decision, but cultural factors are also essential.

In rural China, population mobility is lower, people know each other's backgrounds, resulting in high peer pressure against deviant behavior. Retirement may be one of the things that are on the "forbidden list", because traditionally, it was the privilege of very high-level officers. And even for them, after resigning from imperial court, they usually returned to their native town to help the local education. The urban side, however, is more industrialized and "open-minded" to the concept of retirement. This might explain why there are differences between the rural and urban in terms of the retirement decision. There are also other reasons that can explain the differences, for instance, old people in the rural side can always work on their own field while in the urban side it may be difficult for them to get a job.

4.7.2 Probit Model

As described in section 4.4, the dependent variable, retirement status R_{it}, is a binary variable. A main concern of using a linear probability model with a binary dependent variable is that the estimates are not constrained to the unit interval. As a sensitivity analysis, we fit the sample to a Probit model to see whether there will be a big change. Then, model (4.2) becomes

$$\begin{aligned} y_{it} &= \mathbf{1}(A + \mathit{Enroll}_{it}\Gamma + X'_{it}B + D_i\Delta + \mathit{Wave}_t\Psi + \xi_{it}\varrho + A_i + \varUpsilon_{2,it} > 0) \\ \mathit{Enroll}_{it} &= \mathbf{1}(\alpha_0 + \alpha_1 \mathit{dur}_{it} + \alpha_2 \mathit{fedrev}_{it} + X'_{it}B + D_i\Delta + \mathit{Wave}_t\Psi + \xi_{it} + A_i\rho + \varUpsilon_{1,it} \\ &\qquad > 0) \\ &\text{with} \quad \xi_{it} \sim N(0,1), A_i \sim N(0,\sigma_A), \varUpsilon_{2,it} \sim N(0,1) \quad \text{and} \quad \varUpsilon_{1,it} \sim N(0,1). \end{aligned} \tag{4.3}$$

Here $y_{it} = \mathbf{1}(\cdot)$ means $y_{it} = 1$ if the latent variable in the parentheses is positive, and $\xi_{it}, A_i, \varUpsilon_{2,it}$ and $\varUpsilon_{1,it}$ are uncorrelated with each other.

The variables dur_{it} and fedrev_{it} are the two instruments for pension enrollment status Enroll_{it}. They only affect the dependent variable via the pension enrollment status. Both the retirement status and the enrollment status are affected by the individual effect A_i and the unobserved time-varying component ξ_{it}. The parameters $\varUpsilon_{1,it}$, $\varUpsilon_{2,it}$, A_i and ξ_{it} follow a normal distribution. For convenience, we assume the pension enrollment status is the only variable that is endogenous. The ML estimation results of this model are shown in table (4.14). The coefficients of the pension enrollment status have the same sign in both models. Both models suggest the NRSPI program has a positive effect on the retirement status.

In contrast to the case of the linear probability model, the coefficient estimate of the pension status cannot be interpreted as the marginal effect of the NRSPI program on retirement. We calculate the average marginal effect by taking the average of the marginal effects for each individual in the pooled sample. For each individual, the marginal effect is $\phi(\hat{A}+Enroll_{it}+X'_{it}\hat{B}+D_i\hat{\Delta}+Wave_t\hat{\Psi})-\phi(\hat{A}+X'_{it}\hat{B}+D_i\hat{\Delta}+Wave_t\hat{\Psi})$, where ϕ denotes the probability density function of the standard normal distribution. The average marginal effects amount to 7.39% for the whole sample, 9.85% for the females, and 4.29% for the males. It is consistent with what we find in the linear probability model that the NRSPI program has a more sizable and convincing effect on females than on males. The difference is that the marginal effects are smaller for both groups in the Probit model. Similar to the linear probability model, the effect is only significant for the female group.

4.7.3 Fuzzy Regression Discontinuity Model

Since the pension participants can only receive pension benefits from the NRSPI program when they reach the age of 60, we can use this minimum age requirement in a Fuzzy Regression Discontinuity (FRD) design to estimate the local treatment effect of the pension program. Zhang et al. (2014) and Chen et al. (2015) also adopted this method in their papers. As discussed by Carpenter and Dobkin (2009), Zhang et al. (2014), Chen et al. (2015), and Angrist and Pischke (2008, Chapter 6), the model can be estimated using 2SLS with a pooled sample. The second stage is

$$y_i = \alpha + \rho Pension_i + \beta_0 age_i + \theta X_i + \epsilon_i, \tag{4.4}$$

with y_i the outcome variables, X_i the control variables, which include the control variables that we define in section 4.5 and the second and third order of age. The parameter ρ is the local treatment effect we are interested in. The first stage is

$$Pension_i = \eta_0 + \eta_1 age_i + \eta_2 T_i + \eta_3 X_i + \xi_i, \tag{4.5}$$

with $T_i = 1(age_i \leq 60)$. In another word, we use T_i as instruments to $Pension_i$. The bandwidth, the neighborhood size around the cut-off age 60, determines the sample size in the estimation.

We use the pooled sample to estimate this model. The estimated local treatment effects and the corresponding standard errors using FRD are shown in Table 4.15.

Only the coefficients on *Pension* are presented in the table for the sake of convenience. The whole table is available upon request. Consistent with the findings from model (4.1), the effect of the NRSPI program on retirement status and labor supply situation is not significant for males, no matter which bandwidth is chosen. The effect on females, however, depends on the bandwidth. With a bandwidth equal to 10 years, the probability of retirement will increase by 14.9% for female pensioners. The effect on retirement status is not significantly different from zero when choosing other bandwidths. With a very narrow bandwidth (3 years) or very wide bandwidth (20 years), the sign of the coefficient of receiving pension is even negative. The effect on the females' labor supply is also dependent on the chosen bandwidth. Only when the bandwidth is equal to 5 years, the effect is significantly different from zero. Female pensioners will decrease their weekly labor supply by 18.1 hours.

The magnitude of the only significant coefficient on retirement status matches the results found by Chen et al. (2015), which is varying from 13.2% to 16.2% for different control variable specifications. The effect on retirement status found by Zhang et al. (2014) varies from 16.3% to 26% for different bandwidth. The 90% confidence interval of the effect on retirement status with bandwidth equal to 10 years is $(3.4\%, 43.2\%)$, which contains our point estimation of 14.9%.

The estimation results from the FRD model are very sensitive to the bandwidth; this is one of the reasons that we prefer our model over this model. Another reason is that the NRSPI program not only has an effect on the retirement status of participants above age 60, who have already received pension, but also on contributors below age 60. Thus, the local treatment effect is not very representative for the whole sample. Although there is a big jump in terms of probability to receive pension at the cutoff age, the change in labor supply and retirement status is small at the cutoff age. It further indicates that it is the fact of being in the pension program, being taken care of by the government, that matters for retirement decision making.

4.8 Conclusion

In this paper, we investigated the effect of the New Rural Social Pension Insurance program on the retirement behavior and the labor supply situation of the Chinese elderly. Our findings confirm that the labor force participation is correlated to the social security programs, as is shown by Gruber and Wise (2008) in their *Social Security and Retirement around the World* project. With a monthly pension benefit of less than 100 CNY, less than one-half of the minimum cost of living, the pension program significantly changes the retirement pattern of females. Their retirement likelihood is increased and weekly working hours are decreased. But for males, the labor supply situation does not change significantly.

The amount of the basic pension received has no effect on the retirement pattern. The variation in the basic pension is low and the overall pension income is not sufficient to shift the retirement behavior. It seems it is the feeling that the government will support them in their old age, rather than the amount of money received that affects people's retirement decision. However, to verify this explanation, a structural model is needed in future research.

Although the NRSPI changes the retirement pattern of the rural villagers, there are still substantial differences between the rural area and the urban area. Retirement is a relatively new concept for the rural villagers; it is not easy for them to abandon the tradition of working until too old to work.

We also find that people tend to work more when they have single sons. Although people in the rural side still mainly rely on their adult sons for old age support, they need to work harder to help their sons get married. This is consistent with the finding by Wei et al., (see Wei and Zhang (2011)) that families with unmarried sons tend to save more to increase their son's attractiveness in the marriage market.

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4.9 Appendix

4.9.1 Instrumental Variables

In this part, we want to validate the choice of the instrumental variables. Table 4.16 presents the first stage estimation results of the pooled OLS model in column (2), (4), and (6), as well as the random effect model in columns (1), (3), and (5).

The pooled OLS and the random effect model produce similar results. The coefficients of duration and province level federal revenue on pension enrollment and pension income are significant at the 1% significance level in both models. Longer duration is associated with higher probability of joining the pension program and higher pension income. The impact of federal revenue is negative on pension enrollment while positive on pension income, indicating that the pension program was first introduced in relatively poor provinces, but those provinces fail to provide higher basic pension or higher subsidies. The effect of financial assets shows a similar pattern. People with more financial assets are less likely to join the pension program, but when they participate, they tend to choose a higher level of contribution. The negative correlation between financial assets and the probability of pension enrollment suggests that there is some substitution effect. People have different methods of provision for old age, and the NRSPI is a substitute for individual saving.

Most of the health indicators are significant at the 1% significance level when explaining the self-reported health condition. In addition, by using instrumental variables, we decrease the dimension of health to one: the self-reported health condition, which is powerful in explaining work capacity.

4.10 Figures and Tables

In this section we present a list of figures and tables.

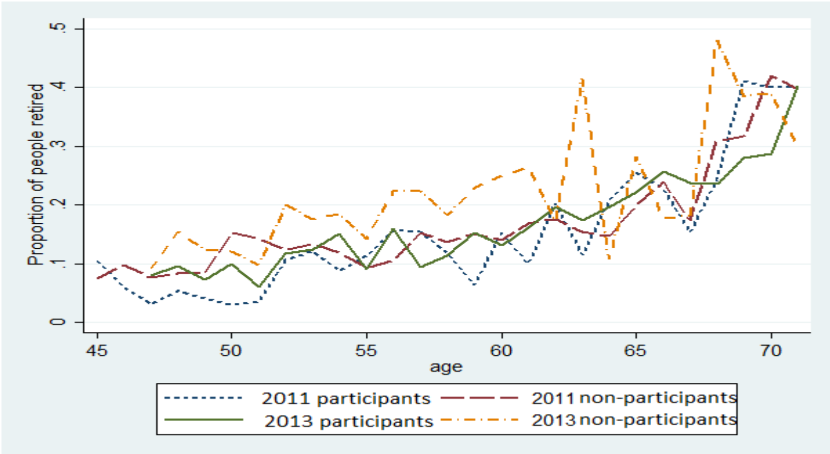


Figure 4.1: Retirement ratio of different age groups by pension status and wave. The dotted line represents pension participants in the first wave. The solid line represents pension participants in the second wave. The dashed line represents non-participants in the first wave. The dash-dotted line represents non-participants in the second wave. Pension participants are those participating in the NRSPI; they can be either contributors or pensioners. Both males and females, both rural and urban samples are included in this plot. The x-axis refers to the age of the individuals, and the y-axis refers to the proportion of people in retirement.

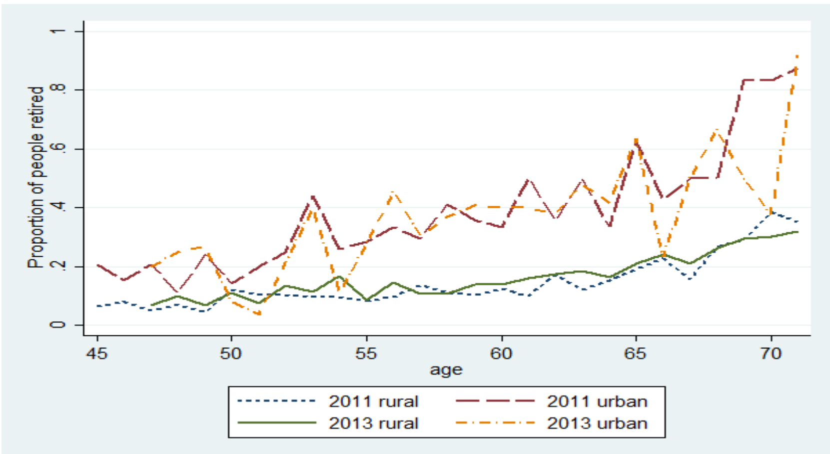


Figure 4.2: Retirement ratio of different age groups by region and wave. The dotted line represents individuals in the rural area in the first wave. The solid line represents individuals in the rural area in the second wave. The dashed line represents individuals in the urban area in the first wave. The dash-dotted line represents individuals in the urban area in the second wave. Both males and females are included in this plot. The x-axis refers to the age of the individuals, and the y-axis refers to the proportion of people in retirement.

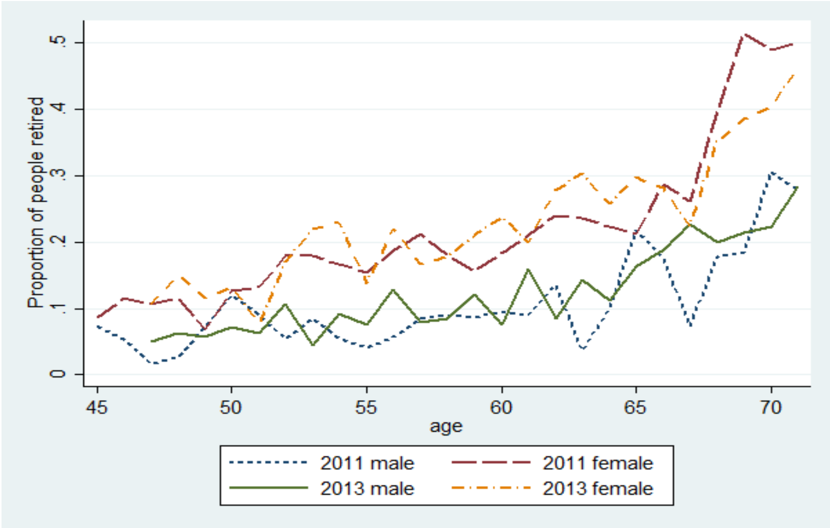


Figure 4.3: Retirement ratio of different age groups by gender and wave. The dotted line represents males in the first wave. The solid line represents males in the second wave. The dashed line represents females in the first wave. The dash-dotted line represents females in the second wave. Individuals from both the urban and the rural areas are included in this plot. The x-axis refers to the age of the individuals, and the y-axis refers to the proportion of people in retirement.

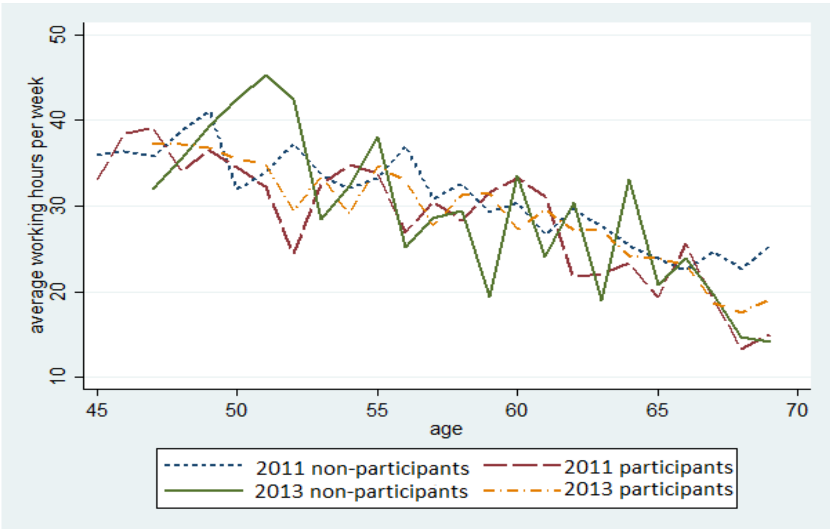


Figure 4.4: The average working hours per week by pension status and wave. The dotted line represents non-participants in the first wave. The solid line represents non-participants in the second wave. The dashed line represents participants in the first wave. The dash-dotted line represents participants in the second wave. Pension participants are those participating in the NRSPI; they can be either contributors or pensioners. Both males and females, both rural and urban samples are included in this plot. The x-axis refers to the age of the individuals, and the y-axis refers to the average working hours per week.

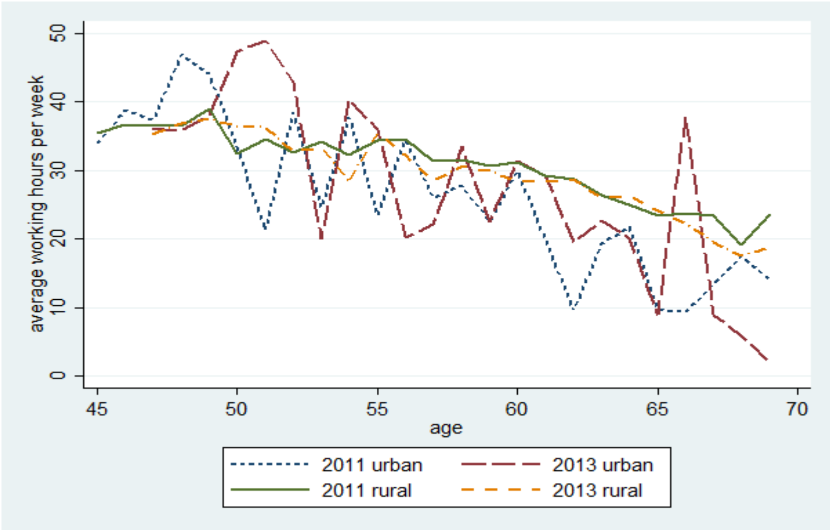


Figure 4.5: The average working hours per week by region and wave. The dotted line represents urban individuals in the first wave. The solid line represents rural individuals in the first wave. The dashed line represents urban individuals in the first wave. The dash-dotted line represents rural individuals in the second wave. Both males and females are included in this plot. The x-axis refers to the age of the individuals, and the y-axis refers to the average working hours per week.

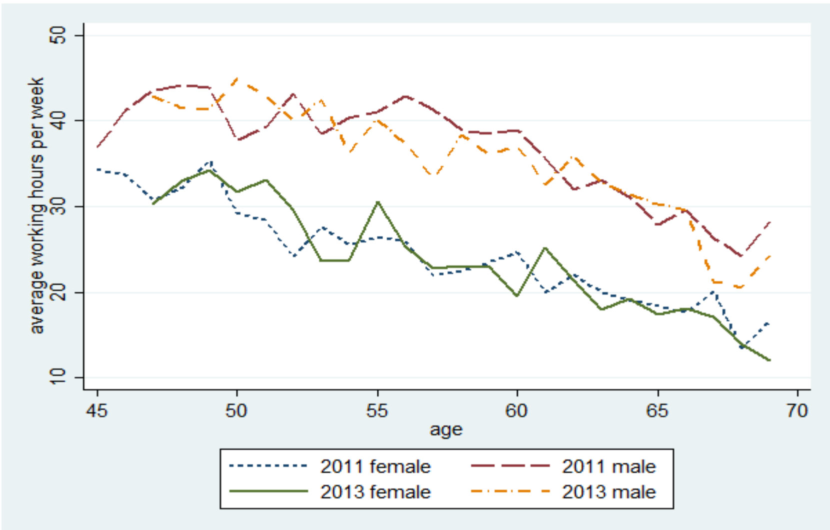


Figure 4.6: The average working hours per week by gender and wave. The dotted line represents females in the first wave. The solid line represents females in the second wave. The dashed line represents males in the first wave. The dash-dotted line represents males in the second wave. Individuals from both the urban and the rural areas are included in this plot. The x-axis refers to the age of the individuals, and the y-axis refers to the average working hours per week.

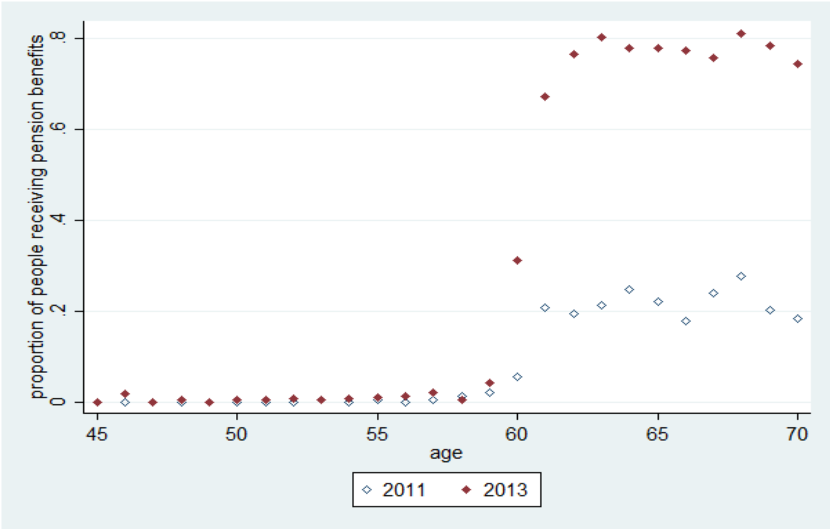


Figure 4.7: The proportion of people who receive pension benefits. The hollow diamond represents the proportion in the first wave, and the solid diamond represents the proportion in the second wave. Both males and females, both urban and rural samples are included in this plot. The x-axis refers to the age of the individuals, and the y-axis refers to the proportion of people who receive pension benefits.

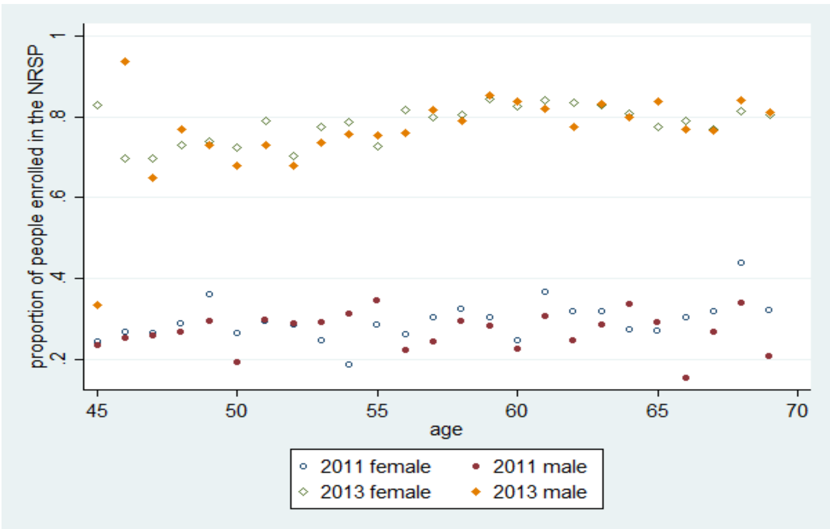
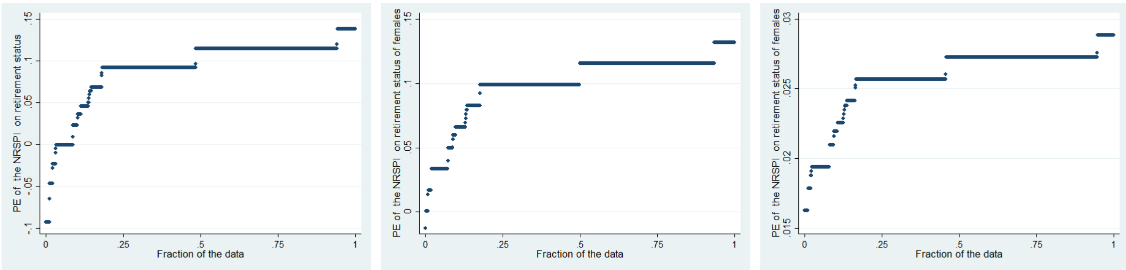
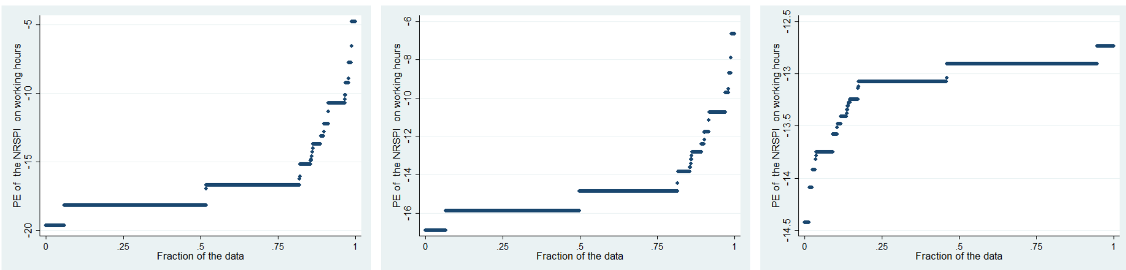


Figure 4.8: The proportion of people who enrolled in the New Rural Social Pension Insurance program by gender and wave. The hollow circle represents females in the first wave, and the solid circle represents males in the first wave. The hollow diamond represents females in the second wave, and the solid diamond represents males in the second wave. Both urban and rural samples are included in this plot. The x-axis refers to the age of the individuals, and the y-axis refers to the proportion of people who participate in the NRSPI.



(a) All (b) Female (c) Male

Figure 4.9: Partial effect of receiving pension on the retirement probability. These figures plot the ordered values of $\hat{\gamma} + \hat{\theta} \times Benefits_{it}$ against the uniform distribution, where $\hat{\gamma}$ and $\hat{\theta}$ denote the estimated values of parameters in model (4.1) when the dependent variable is the retirement status. The x-axis is the fraction of the data and the y-axis displays the partial effect. Panels (a), (b), and (c) show the partial effect for the whole sample, the female subsample, and the male subsample, respectively.



(a) All (b) Female (c) Male

Figure 4.10: Partial effect of receiving pension on the labor supply. These figures plot the ordered values of $\hat{\gamma} + \hat{\theta} \times Benefits_{it}$ against the uniform distribution, where $\hat{\gamma}$ and $\hat{\theta}$ denote the estimated values of parameters in model (4.1) when the dependent variable is the number of weekly working hours. The x-axis refers to the fraction of the data and the y-axis displays the partial effect. Panels (a), (b), and (c) show the partial effect for the whole sample, the female subsample, and the male subsample, respectively.

	(1) Female		(2) Male		(3) Overall	
	Mean	Obs.	Mean	Obs.	Mean	Obs.
Dependent variables						
retired(%)	21.9	5884	13.3	5416	17.8	11300
non-agri. work(%)	14.9	5884	30	5416	22.2	11300
agri. work(%)	72.3	5884	77.5	5416	74.8	11300
weekly working hours(H)	23.2	5667	33.8	5183	28.3	10850
w.h. on non-agri work(H)	6.5	5823	14.9	5319	10.5	11142
w.h. on agri. work(H)	16.8	5722	18.7	5271	17.7	10993
w.h. on own field(H)	16.2	5748	18	5312	17.1	11060
Pension						
pension enrollment(%)	52.9	5884	51.6	5416	52.3	11300
receive pension(%)	20.8	5884	21.4	5416	21.1	11300
benefits(CNY/year)	860	1222	853.2	1160	856.8	2382
Demography						
male(%)		5884		5416	47.9	11300
married(%)	86.5	5884	90.8	5416	88.5	11300
agri.-hukou(%)	98.9	5884	98.8	5416	98.8	11300
education	2.4	5884	3.5	5416	2.9	11300
age	58.4	5884	59.4	5416	58.9	11300
Geography						
East(%)	28.2	5884	27.8	5416	28	11300
West(%)	36.7	5884	36.4	5416	36.6	11300
Northeast(%)	4.7	5884	4.9	5416	4.8	11300
Middle(%)	30.4	5884	30.9	5416	30.6	11300

Table 4.1: The sample averages of the main variables. All variables are expressed as percentages except *age*, *education*, *working hours*, *benefits*, *health*, which is the self-reported health status, and *financial situation*. The column (1) represents the female subsample, the column (2) represents the male subsample, and column (3) includes both males and females.

	Female		Male		Overall	
	Mean	Obs	Mean	Obs	Mean	Obs
Occupation						
farming(%)	92.5	5884	89.5	5416	91	11300
government(%)	1	5884	2	5416	1.5	11300
firm(%)	2	5884	4.7	5416	3.3	11300
other employed(%)	7.2	5884	14.7	5416	10.8	11300
self-employed(%)	6.3	5884	10.1	5416	8.1	11300
Family Obligation						
care child(%)	20.9	5884	21.5	5416	21.2	11300
care parent (%)	6.6	5884	5.9	5416	6.3	11300
Health Situation						
self-reported health	1.9	5884	2.1	5416	2	11300
Financial Situation						
h.h. income (CNY/year)	11872.2	5884	14576.3	5416	13168.3	11300
financial asset (CNY)	4156.8	5884	7036.3	5416	5536.9	11300
financial liability (CNY)	2331.8	5884	3043.6	5416	2673	11300

Table 4.1 continued. The variables *care child* and *care parent* indicate whether survey participants have a grandchild under 6 or old parents to take care of. The variable *self-reported health* denotes the self-reported health condition, which varies from 0 (very poor) to 5 (excellent).

	retired	hours	pension	benefits	health	married	hukou
retired	1						
hours	-0.4553	1					
pension	0.1532	-0.1477	1				
benefits	0.0934	-0.0808	0.6456	1			
health	-0.139	0.1215	-0.0422	-0.0183	1		
married	-0.2105	0.1442	-0.1427	-0.0746	0.0465	1	
hukou	-0.0249	0.0056	0.011	0.0089	-0.014	-0.0235	1
single son	-0.0762	0.0858	-0.0956	-0.0589	-0.0045	0.0503	0.0167
single dau.	-0.0556	0.0695	-0.1142	-0.0691	0.0121	0.0793	0.011
farm	-0.0156	-0.1612	0.0783	0.0358	-0.0909	-0.0299	0.0463
government	0.0381	0.0411	-0.0023	0.0008	0.0117	0.0219	-0.0227
firm	0.0591	0.1023	-0.027	-0.0097	0.0312	0.0057	-0.0275
ind. firm	-0.0107	0.2915	-0.0893	-0.0425	0.0851	0.0314	0.0042
self emp.	-0.103	0.2941	-0.0606	-0.0233	0.093	0.0356	-0.0338
hh income	-0.074	0.1352	-0.1179	-0.0784	0.0813	0.0302	-0.0016
education	-0.1467	0.1678	-0.1666	-0.0946	0.1242	0.1639	-0.0321
age	0.3408	-0.2637	0.4927	0.3062	-0.1158	-0.3172	0.0032
fin. asset	-0.0374	0.0725	-0.0458	-0.0046	0.1026	0.0575	-0.0137
fin. Liab.	-0.0056	0.0212	-0.0258	-0.0159	-0.0012	0.0237	0.005
male	-0.1137	0.179	0.0099	0.0069	0.0882	0.0684	-0.0032

	single son	single dau.	farm	government	firm	ind. firm	self emp.
single son	1						
single dau.	0.147	1					
farm	-0.0416	-0.0707	1				
government	-0.012	0.0165	-0.1517	1			
firm	0.0128	0.0265	-0.1835	0.0209	1		
ind. firm	0.0445	0.0358	-0.2993	-0.0339	-0.03	1	
self emp.	0.0322	0.0571	-0.3302	-0.0328	-0.047	-0.0693	1
hh income	0.0412	0.0582	-0.1236	0.0136	0.0513	0.1106	0.0792
education	0.1072	0.1245	-0.1491	0.0626	0.0944	0.1388	0.1235
age	-0.1984	-0.2139	0.1416	-0.0131	-0.0479	-0.1528	-0.1222
fin. asset	0.028	0.0681	-0.1151	0.0201	0.0371	0.0337	0.13
fin. Liab.	0.0235	0.0107	-0.0416	0.0031	0.0048	0.0048	0.0331
male	0.0067	0.01	-0.0515	0.0364	0.0748	0.1201	0.0706

	hh income	education	age	fin. asset	fin. Liab.	male
hh income	1					
education	0.1341	1				
age	-0.1773	-0.337	1			
fin. asset	0.1192	0.1177	-0.0929	1		
fin. Liab.	0.0349	0.0421	-0.0672	0.0297	1	
male	0.0514	0.3367	0.0547	0.061	0.014	1

Table 4.1 continued. Correlation matrix of the main variables.

	(1)	(2)	(3)	(4)	(5)	(6)
	Retirement Status			weekly working hours		
	All	Male	Female	All	Male	Female
pension	0.369**	0.045	0.296**	−34.562***	−11.048	−27.155**
	(0.15)	(0.15)	(0.15)	(11.10)	(14.60)	(11.881)
pension × benefits	−0.384**	−0.026	−0.273**	24.819**	−2.815	17.088
	(0.17)	(0.17)	(0.14)	(11.42)	(15.34)	(11.217)
self-reported health	−0.201***	−0.232***	−0.167***	8.048***	10.838***	5.528***
	(0.02)	(0.02)	(0.02)	(0.87)	(1.30)	(1.157)
married	−0.110***	−0.129***	−0.103***	5.789***	11.613***	2.384**
	(0.02)	(0.03)	(0.02)	(1.01)	(1.75)	(1.197)
agri-hukou	−0.101**	−0.092	−0.125*	5.792**	7.240**	5.992
	(0.04)	(0.07)	(0.07)	(2.74)	(3.68)	(3.803)
male	−0.084***			6.487***		
	(0.01)			(0.69)		
no. never married sons	−0.024**	−0.013	−0.030**	2.073***	2.593**	1.443
	(0.01)	(0.01)	(0.01)	(0.73)	(1.02)	(1.001)
no. never married daughters	0.018	0.004	0.03	−0.953	−1.012	−0.908
	(0.01)	(0.02)	(0.02)	(0.92)	(1.23)	(1.353)
farming	−0.051***	−0.029	−0.073***	10.898***	12.639***	7.178***
	(0.02)	(0.02)	(0.03)	(1.45)	(1.85)	(2.262)
government	0.126***	0.090**	0.182***	17.215***	20.680***	11.428*
	(0.04)	(0.04)	(0.06)	(3.95)	(4.59)	(5.91)
firm	0.154***	0.165***	0.127***	21.323***	23.321***	18.017***
	(0.03)	(0.03)	(0.04)	(2.47)	(3.06)	(3.802)
individual firm	0.076***	0.060***	0.095***	28.872***	32.447***	23.396***
	(0.01)	(0.01)	(0.02)	(1.42)	(1.68)	(2.602)
self-employed	−0.044***	−0.012	−0.097***	34.012***	33.640***	34.348***
	(0.01)	(0.02)	(0.03)	(1.63)	(2.04)	(2.498)
household income	−0.121	0.12	−0.246	41.760***	34.808*	35.451*
	(0.15)	(0.18)	(0.22)	(13.85)	(20.42)	(18.982)
education	0.009***	0.005	0.010**	−0.793***	−0.491	−0.990***
	(0.00)	(0.00)	(0.01)	(0.22)	(0.31)	(0.275)
age	0.106***	0.091***	0.115***	−1.784	0.057	−3.354**
	(0.02)	(0.03)	(0.02)	(1.19)	(1.74)	(1.47)
financial asset	0.592***	0.415*	0.649*	−32.520*	−23.974	−28.808
	(0.22)	(0.24)	(0.34)	(18.19)	(23.68)	(29.523)
financial liability	0.017	−0.136	0.036	4.402	31.45	0.199
	(0.15)	(0.18)	(0.16)	(7.67)	(24.49)	(4.902)
east	0.071***	0.043**	0.071***	−3.001***	−1.566	−2.403*
	(0.02)	(0.02)	(0.02)	(1.07)	(1.51)	(1.401)
west	−0.022*	−0.016	−0.042**	2.722***	2.456*	4.102***
	(0.01)	(0.02)	(0.02)	(0.91)	(1.27)	(1.112)
northeast	0.057***	0.056**	0.060*	−4.691***	−5.016**	−4.429**
	(0.02)	(0.03)	(0.04)	(1.41)	(2.18)	(−1.758)
wave dummy	0.007	0.022	−0.006	2.016	1.489	2.273
	(0.02)	(0.03)	(0.03)	(1.49)	(2.19)	(1.862)
Observations	11300	5416	5884	10428	4966	5462
χ^2	1222.831	533.640	699.149	2450.440	1489.345	860.718

Table 4.2: The effect of NRSPI program on the retirement status and weekly working hours. We fit model (4.1) to the rural observations with age above 45 in these regressions. In columns (1), (2), and (3), the dependent variable is the retirement status; in columns (4), (5), and (6), it is working hours per week. Columns (1) and (4) use all rural observations, columns (2) and (5) use only the male rural observations, and columns (3) and (6) use only the female rural observations. The constant terms and coefficients on the number of sons and daughters, and whether individuals need to take care of grandchildren or parents are omitted from the report.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	hours non-agri. work			hours agri. work			hours agri. work for own hh.		
	All	Male	Female	All	Male	Female	All	Male	Female
pension	−5.631	6.027	−5.049	−26.034***	−17.277*	−23.671**	−24.953***	−17.134*	−21.572**
	(6.04)	(8.63)	(6.30)	(8.00)	(10.00)	(9.51)	(8.00)	(9.57)	(9.172)
pension	5.657	−7.412	5.804	17.627**	4.058	12.845	19.061**	8.367	12.055
× benefits	(5.73)	(9.77)	(5.18)	(8.75)	(11.02)	(8.83)	(8.99)	(10.90)	(8.491)
self-reported	2.235***	3.169***	1.622***	5.718***	7.727***	3.858***	5.360***	7.440***	3.384***
health	(0.48)	(0.87)	(0.57)	(0.72)	(0.98)	(0.96)	(0.71)	(0.98)	(0.948)
married	0.691	3.485***	−0.467	4.977***	8.153***	2.957***	4.798***	7.579***	2.973***
	(0.55)	(1.15)	(0.61)	(0.79)	(1.30)	(1.00)	(0.78)	(1.28)	(0.982)
agri-hukou	−0.399	2.081	−1.943	6.245***	5.278*	7.980***	5.821***	4.598	7.755***
	(2.18)	(2.63)	(3.41)	(1.80)	(2.94)	(2.18)	(1.78)	(2.95)	(2.149)
male	2.533***			3.869***			3.678***		
	(0.40)			(0.54)			(0.54)		
no. never	0.42	0.591	0.501	1.545***	1.974**	0.977	1.597***	2.123***	0.924
married sons	(0.41)	(0.68)	(0.53)	(0.57)	(0.77)	(0.81)	(0.56)	(0.76)	(0.779)
no. never	−0.286	−0.597	0.087	−0.562	−0.567	−0.812	−0.168	−0.229	−0.252
married dau.	(0.55)	(0.87)	(0.70)	(0.73)	(0.99)	(1.06)	(0.72)	(0.97)	(1.054)

Table 4.3: The effect of NRSPI program on the weekly working hours for different types of work. We fit model (4.1) to the rural observations with age above 45 in these regressions. In columns (1), (2), and (3), the dependent variable is the weekly non-agricultural working hours; in columns (4), (5), and (6), it is the agricultural working hours per week; and in columns (7), (8), and (9) it is the own-field agricultural working hours per week. Columns (1), (4), and (7) use all rural observations, columns (2), (5), and (8) use only the male rural observations, and columns (3), (6), and (9) use only the female rural observations. The constant terms and coefficients on the district and wave dummies, the financial liabilities, number of sons and daughters, and whether individuals need to take care of grandchildren or parents are omitted from the report.

farming	−3.301***	−2.959***	−4.897**	14.246***	15.181***	12.915***	13.445***	14.336***	12.232***
	(1.26)	(1.03)	(1.91)	(0.65)	(1.17)	(1.04)	(0.65)	(1.14)	(0.984)
government	25.127***	28.524***	19.777***	−7.596***	−7.794***	−7.808***	−6.911***	−7.197***	−6.938***
	(3.54)	(2.04)	(5.86)	(1.33)	(2.33)	(1.54)	(1.33)	(2.27)	(1.481)
firm	31.697***	34.625***	26.332***	−9.876***	−11.094***	−8.419***	−9.205***	−10.170***	−7.838***
	(2.19)	(1.32)	(3.65)	(0.98)	(1.51)	(1.63)	(0.96)	(1.46)	(1.516)
individual	38.664***	42.739***	31.228***	−9.158***	−10.484***	−7.363***	−8.771***	−10.048***	−6.767***
firm	(1.16)	(0.87)	(1.99)	(0.78)	(1.00)	(1.45)	(0.74)	(0.97)	(1.309)
self-employed	41.161***	41.338***	39.871***	−6.123***	−7.840***	−4.530***	−5.439***	−6.963***	−3.850***
	(1.28)	(0.99)	(2.01)	(0.90)	(1.14)	(1.27)	(0.87)	(1.10)	(1.230)
household	45.808***	55.080***	23.888**	0.561	−20.953*	19.59	−4.047	−21.722*	10.456
income	(8.68)	(10.36)	(10.06)	(10.54)	(11.87)	(14.90)	(9.11)	(11.52)	(12.156)
education	0.077	0.039	0.179	−0.889***	−0.535**	−1.200***	−0.861***	−0.489**	−1.178***
	(0.13)	(0.20)	(0.16)	(0.17)	(0.22)	(0.22)	(0.16)	(0.22)	(0.214)
age	−1.476**	−1.631	−1.312*	−0.597	1.8	−1.958	−0.717	1.416	−1.901
	(0.67)	(1.17)	(0.79)	(0.95)	(1.32)	(1.22)	(0.94)	(1.31)	(1.195)
financial	−6.804	−4.595	−11.474	−23.571**	−17.641	−20.561	−28.789***	−25.231**	−22.734
asset	(15.00)	(10.10)	(21.79)	(10.86)	(11.47)	(19.83)	(9.79)	(11.26)	(19.525)
Observations	10428	4966	5462	10428	4966	5462	10428	4966	5462
χ^2	4254.056	6204.680	1166.986	1971.002	813.546	943.394	1836.448	755.503	956.580

Table 4.3 continued.

	(1) All	(2) Male	(3) Female	(4) All	(5) Male	(6) Female
	retirement status			non-agr. work status		
benefits	−0.107	0.025	−0.136	0.012	0.011	0.010
	(0.070)	(0.085)	(0.092)	(0.032)	(0.051)	(0.022)
self-reported health	−0.277***	−0.296***	−0.233***	0.036***	0.055***	0.018
	(0.029)	(0.036)	(0.043)	(0.012)	(0.018)	(0.014)
male	−0.096***			0.032***		
	(0.022)			(0.011)		
no. never married sons	−0.064**	−0.039	−0.059	0.002	−0.004	0.007
	(0.026)	(0.033)	(0.045)	(0.009)	(0.014)	(0.014)
Observations	2382	1160	1222	2382	1160	1222
	agriculture work status			agr. work for own household		
benefits	0.110	−0.024	0.133	−0.034	0.014	−0.092
	(0.070)	(0.083)	(0.093)	(0.047)	(0.028)	(0.120)
self-reported health	0.275***	0.286***	0.237***	0.114**	0.129**	0.122*
	(0.029)	(0.035)	(0.042)	(0.045)	(0.061)	(0.069)
male	0.092***			0.040		
	(0.022)			(0.037)		
no. never married sons	0.063**	0.042	0.056	0.040	0.060	0.022
	(0.026)	(0.032)	(0.045)	(0.036)	(0.060)	(0.049)
Observations	2382	1160	1222	416	208	208

Table 4.4: The effect of pension benefits on the retirement status and work status of different types of work. We fit model (4.1) to the rural pensioners in these regressions. In the top panel, in columns (1) to (3), the dependent variable is the retirement status, and in columns (4) to (6), it is the non-agricultural work status. In the bottom panel, in columns (1) to (3), the dependent variable is the agricultural work status, and in columns (4) to (6), it is the own-field agricultural work status. Columns (1) and (4) use all rural pensioners, columns (2) and (5) use only the male rural pensioners, and columns (3) and (6) use only the female rural pensioners. Other coefficients are omitted from the report.

	(1) All	(2) Male	(3) Female	(4) All	(5) Male	(6) Female
	weekly working hours			hours non-agri. work		
benefits	2.365	−4.283	3.672	0.031	−2.343	1.919
	(3.450)	(6.102)	(3.788)	(2.019)	(3.588)	(1.403)
self-reported health	7.233***	8.830***	5.072***	1.497**	1.911	0.880
	(1.379)	(2.071)	(1.837)	(0.754)	(1.310)	(0.778)
male	6.475***			1.771***		
	(1.129)			(0.635)		
no. never married sons	2.500*	2.437	1.153	0.133	−0.812	0.425
	(1.329)	(2.011)	(1.997)	(0.676)	(1.317)	(0.885)
Observations	2241	1087	1154	2241	1087	1154
	hours agri. work			hours agri. work for own household		
benefits	2.282	−2.061	1.723	2.557	−1.128	1.756
	(2.863)	(4.422)	(3.374)	(2.853)	(4.383)	(3.361)
self-reported health	5.710***	6.888***	4.182**	5.481***	6.912***	3.654**
	(1.196)	(1.615)	(1.811)	(1.172)	(1.600)	(1.798)
male	4.713***			4.690***		
	(0.906)			(0.903)		
no. never married sons	2.355**	3.218**	0.734	2.453**	3.519**	0.677
	(1.147)	(1.623)	(1.681)	(1.143)	(1.609)	(1.673)
Observations	2241	1087	1154	2241	1087	1154

Table 4.5: The effect of pension benefits on the weekly working hours of different types of work. We fit model (4.1) to the rural pensioners in these regressions. In the top panel, in columns (1) to (3), the dependent variable is the total working hours per week; in columns (4) to (6), it is the non-agricultural working hours per week. In the bottom panel, in columns (1) to (3), the dependent variable is the agricultural working hours per week; in columns (4) to (6), it is the own-field agricultural working hours per week. Columns (1) and (4) use all rural pensioners, columns (2) and (5) use only the male rural pensioners, and columns (3) and (6) use only the female rural pensioners. Other coefficients are omitted from the report.

	(1)	(2)	(3)	(4)	(5)	(6)
		retirement status			non-agr. work status	
	All	Male	Female	All	Male	Female
prev. year pension enrollment	0.113**	0.037	0.166**	−0.051	−0.107**	0.016
	(0.048)	(0.057)	(0.068)	(0.033)	(0.051)	(0.042)
self-reported health	−0.140***	−0.150***	−0.131***	0.040***	0.063***	0.027**
	(0.017)	(0.027)	(0.020)	(0.011)	(0.017)	(0.013)
married	−0.044*	−0.130***	0.036	−0.011	0.037*	−0.049**
	(0.024)	(0.036)	(0.033)	(0.015)	(0.022)	(0.019)
agri-hukou	−0.132**	−0.146*	−0.137*	0.043	0.098***	0.008
	(0.056)	(0.084)	(0.072)	(0.026)	(0.036)	(0.036)
male	−0.054***			0.047***		
	(0.010)			(0.008)		
no. never married sons	−0.022***	−0.008	−0.035***	−0.002	−0.007	0.007
	(0.008)	(0.011)	(0.012)	(0.007)	(0.012)	(0.009)
no. never married daughters	0.008	0.008	0.006	0.002	0.004	0.001
	(0.011)	(0.012)	(0.016)	(0.009)	(0.013)	(0.011)
farming	−0.082***	−0.048**	−0.119***	0.027	0.038*	0.006
	(0.019)	(0.020)	(0.027)	(0.017)	(0.021)	(0.029)
government	0.055	−0.007	0.171***	0.735***	0.850***	0.574***
	(0.043)	(0.037)	(0.064)	(0.059)	(0.064)	(0.112)
firm	0.057**	0.069**	0.049	0.714***	0.728***	0.686***
	(0.025)	(0.029)	(0.039)	(0.036)	(0.043)	(0.065)
individual firm	0.038***	0.027*	0.060**	0.773***	0.802***	0.717***
	(0.013)	(0.014)	(0.024)	(0.016)	(0.019)	(0.029)
self-employed	−0.049***	−0.014	−0.097***	0.862***	0.843***	0.885***
	(0.012)	(0.014)	(0.025)	(0.013)	(0.019)	(0.019)
household income	−0.011	−0.036	0.073	0.318**	0.505***	0.058
	(0.148)	(0.169)	(0.229)	(0.127)	(0.193)	(0.180)
education	−0.001	0.002	−0.001	0.001	−0.001	0.002
	(0.003)	(0.004)	(0.004)	(0.002)	(0.004)	(0.003)
age	0.022**	0.003	0.037**	−0.009	−0.008	−0.011
	(0.011)	(0.013)	(0.018)	(0.009)	(0.013)	(0.012)
financial asset	0.380**	0.449**	0.245	−0.247	−0.399**	−0.021
	(0.187)	(0.227)	(0.307)	(0.154)	(0.181)	(0.195)
financial liability	0.025	−0.283*	0.085	−0.061	−0.054	−0.066
	(0.159)	(0.150)	(0.142)	(0.085)	(0.246)	(0.084)
east	0.050***	0.039**	0.058***	−0.014	−0.031**	0.007
	(0.015)	(0.018)	(0.022)	(0.011)	(0.015)	(0.015)
west	−0.029**	−0.008	−0.044**	−0.011	−0.036**	0.013
	(0.013)	(0.016)	(0.021)	(0.009)	(0.015)	(0.012)
northeast	0.037*	0.013	0.070*	−0.018	−0.042*	0.003
	(0.021)	(0.022)	(0.037)	(0.015)	(0.023)	(0.020)
wave dummy	−0.050*	−0.007	−0.077*	0.021	0.057*	−0.024
	(0.027)	(0.033)	(0.039)	(0.019)	(0.030)	(0.024)
Observations	6362	2962	3400	6362	2962	3400
χ^2	254.929	87.101	156.987	12058.464	6050.487	5224.082

Table 4.6: The effect of NRSPI program on the retirement status and work status of non-agriculture work. We fit model (4.2) to rural observations with age below 60 in these regressions. In columns (1) to (3), the dependent variable is the retirement status; in columns (4) to (6) it is the non-agricultural work status. Columns (1) and (4) use all rural observations below age 60, columns (2) and (5) use only the male rural observations below age 60, and columns (3) and (6) use only the female rural observations below age 60. The constant terms and coefficients on the number of sons and daughters, and whether individuals need to take care of grandchildren or parents are omitted from the report.

	(1)	(2)	(3)	(4)	(5)	(6)
	agriculture work status			agr. work for own hh.		
	All	Male	Female	All	Male	Female
prev. year pension enrollment	−0.066	0.027	−0.139**	−0.111***	−0.087	−0.109**
	(0.043)	(0.048)	(0.067)	(0.040)	(0.059)	(0.052)
self-reported health	0.132***	0.133***	0.127***	0.016	0.020	0.009
	(0.016)	(0.025)	(0.022)	(0.013)	(0.021)	(0.017)
married	0.037*	0.083***	−0.011	0.002	0.014	−0.011
	(0.022)	(0.032)	(0.029)	(0.021)	(0.035)	(0.025)
agri-hukou	0.123**	0.120	0.143**	−0.039	−0.018	−0.063***
	(0.053)	(0.081)	(0.066)	(0.032)	(0.068)	(0.020)
male	0.044***			0.005		
	(0.009)			(0.010)		
no. never married sons	0.024***	0.010	0.036***	0.015*	0.020*	0.012
	(0.008)	(0.010)	(0.011)	(0.008)	(0.011)	(0.011)
no. never married daughters	−0.000	−0.001	0.001	−0.002	0.005	−0.008
	(0.010)	(0.010)	(0.016)	(0.011)	(0.015)	(0.016)
farming	0.909***	0.939***	0.861***	0.335	−0.095**	0.751***
	(0.012)	(0.013)	(0.021)	(0.296)	(0.041)	(0.061)
government	−0.030	−0.005	−0.110	0.076***	0.068**	0.094***
	(0.031)	(0.028)	(0.068)	(0.027)	(0.033)	(0.017)
firm	−0.056***	−0.049**	−0.071*	0.053***	0.064***	0.025
	(0.021)	(0.024)	(0.038)	(0.020)	(0.022)	(0.042)
individual firm	−0.030***	−0.011	−0.064***	−0.015	−0.013	−0.020
	(0.011)	(0.012)	(0.023)	(0.015)	(0.018)	(0.028)
self-employed	0.010	0.002	0.016	−0.001	0.006	−0.009
	(0.009)	(0.012)	(0.016)	(0.016)	(0.020)	(0.028)
household income	−0.170	−0.201	−0.135	−0.101	−0.140	−0.040
	(0.133)	(0.143)	(0.230)	(0.158)	(0.185)	(0.265)
education	−0.001	−0.004	−0.000	0.001	0.003	−0.000
	(0.003)	(0.003)	(0.004)	(0.003)	(0.004)	(0.004)
age	−0.027***	−0.012	−0.037**	0.008	0.014	−0.001
	(0.010)	(0.012)	(0.016)	(0.011)	(0.016)	(0.017)
financial asset	−0.346***	−0.291*	−0.385	0.045	−0.068	0.372
	(0.134)	(0.158)	(0.266)	(0.193)	(0.226)	(0.368)
financial liability	−0.017	0.245**	−0.065	−0.059	0.206	−0.340
	(0.155)	(0.123)	(0.129)	(0.210)	(0.219)	(0.370)
east	−0.041***	−0.017	−0.061***	−0.022*	−0.013	−0.026
	(0.014)	(0.016)	(0.023)	(0.012)	(0.017)	(0.018)
west	0.029**	0.016	0.037*	−0.008	−0.009	−0.006
	(0.012)	(0.015)	(0.019)	(0.011)	(0.016)	(0.016)
northeast	−0.033*	−0.003	−0.070**	0.020	0.049**	−0.011
	(0.020)	(0.020)	(0.033)	(0.018)	(0.020)	(0.030)
wave dummy	0.023	−0.020	0.056	0.117***	0.100***	0.119***
	(0.025)	(0.028)	(0.038)	(0.026)	(0.038)	(0.034)
Observations	6362	2962	3400	4582	2176	2406
χ^2	15066.913	12880.441	4678.392	89.342	199.374	40621.252

Table 4.7: The effect of NRSPI program on the work status of agriculture work. We fit model (4.2) to the rural observations with age below 60 in these regressions. In columns (1) to (3), the dependent variable is the agricultural work status; in columns (4) to (6) it is the agricultural work status on their own household field. Columns (1) and (4) use all rural observations below age 60, columns (2) and (5) use only the male rural observations below age 60, and columns (3) and (6) use only the female rural observations below age 60. The constant terms and coefficients on the number of sons and daughters, and whether individuals need to take care of grandchildren or parents are omitted from the report.

	(1)	(2)	(3)	(4)	(5)	(6)
	weekly working hours			hours non-agri. work		
	All	Male	Female	All	Male	Female
prev. year pension enrollment	−10.494***	−6.470	−12.425**	−0.511	2.871	−3.016
	(4.069)	(6.396)	(5.092)	(2.622)	(4.303)	(2.968)
self-reported health	5.510***	7.654***	3.904***	2.502***	3.641***	1.563*
	(1.195)	(1.931)	(1.494)	(0.703)	(1.254)	(0.810)
married	4.389**	11.108***	−3.020	1.232	3.764**	−1.744
	(1.743)	(2.451)	(2.327)	(1.020)	(1.852)	(1.291)
agri-hukou	6.446*	7.724	6.571	−3.745	0.469	−6.364
	(3.724)	(4.984)	(5.239)	(2.539)	(3.721)	(4.053)
male	5.270***			2.734***		
	(0.898)			(0.573)		
no. never married sons	2.825***	2.918**	2.885***	0.406	0.858	0.225
	(0.772)	(1.194)	(1.010)	(0.497)	(0.800)	(0.574)
no. never married daughters	−0.067	−0.989	0.995	−0.579	−0.937	−0.059
	(0.923)	(1.330)	(1.286)	(0.609)	(0.984)	(0.671)
farming	12.415***	13.436***	10.246***	−2.906*	−2.482*	−4.148*
	(1.679)	(2.166)	(2.659)	(1.485)	(1.399)	(2.281)
government	22.254***	25.566***	15.977*	30.814***	33.228***	27.456***
	(4.658)	(5.101)	(8.777)	(4.252)	(2.814)	(8.256)
firm	28.458***	30.134***	24.999***	37.666***	40.556***	32.802***
	(2.648)	(3.363)	(4.284)	(2.448)	(1.732)	(4.155)
individual firm	32.605***	34.871***	28.123***	41.938***	45.513***	36.215***
	(1.539)	(1.814)	(2.820)	(1.273)	(1.081)	(2.231)
self-employed	36.232***	34.643***	37.933***	43.230***	43.307***	43.213***
	(1.816)	(2.293)	(2.952)	(1.494)	(1.290)	(2.301)
household income	40.602**	52.708*	22.354	48.748***	71.342***	20.339
	(17.851)	(27.884)	(23.132)	(11.525)	(13.358)	(12.602)
education	−0.357	−0.044	−0.664**	0.309*	0.163	0.413**
	(0.263)	(0.413)	(0.338)	(0.174)	(0.270)	(0.206)
age	1.256	4.624***	−1.460	−0.875	−0.529	−1.206
	(1.018)	(1.541)	(1.345)	(0.630)	(1.046)	(0.745)
financial asset	−14.272	−19.875	−2.476	−16.017	−21.517*	−9.814
	(20.341)	(25.689)	(26.487)	(16.559)	(11.192)	(23.097)
financial liability	2.769	40.597	−4.333	−0.880	16.780	−3.881
	(8.739)	(24.708)	(5.154)	(5.591)	(16.789)	(5.402)
east	−1.664	−0.999	−1.935	−1.569*	−1.400	−1.306
	(1.269)	(1.834)	(1.755)	(0.833)	(1.232)	(1.044)
west	3.904***	2.333	5.010***	−1.139*	−1.598	−0.798
	(1.127)	(1.680)	(1.509)	(0.683)	(1.143)	(0.822)
northeast	−3.202*	−1.699	−5.090**	−0.586	−0.402	−1.168
	(1.804)	(2.783)	(2.284)	(1.211)	(1.967)	(1.273)
wave dummy	4.264*	1.782	5.397*	0.633	−0.769	1.452
	(2.306)	(3.580)	(2.944)	(1.487)	(2.530)	(1.756)
Observations	5802	2686	3116	5802	2686	3116
χ^2	1289.769	758.394	433.970	3478.797	3861.872	1028.622

Table 4.8: The effect of NRSPI program on labor supply. We fit model (4.2) to rural observations with age below 60 in these regressions. In columns (1) to (3), the dependent variable is the total weekly working hours; in columns (4) to (6), it is the weekly non-agricultural working hours. Columns (1) and (4) use all rural observations below age 60, columns (2) and (5) use only the male rural observations below age 60, and columns (3) and (6) use only the female rural observations below age 60. The constant terms and coefficients on the number of sons and daughters, and whether individuals need to take care of grandchildren or parents are omitted from the report.

	(1)	(2)	(3)	(4)	(5)	(6)
	hours agri. work			hours agri. work for own hh.		
	All	Male	Female	All	Male	Female
prev. year pension enrollment	−10.023***	−8.554*	−9.538**	−8.496***	−6.302	−8.714**
	(3.135)	(4.554)	(4.062)	(2.999)	(4.374)	(3.824)
self-reported health	2.811***	3.812***	2.229*	2.595***	3.974***	1.733
	(0.946)	(1.380)	(1.201)	(0.912)	(1.329)	(1.180)
married	3.120**	7.479***	−1.227	2.726**	6.471***	−1.218
	(1.376)	(2.017)	(2.007)	(1.356)	(1.942)	(1.992)
agri-hukou	10.229***	7.159*	13.024***	9.359***	5.981	12.489***
	(2.305)	(4.144)	(2.400)	(2.271)	(3.993)	(2.420)
male	2.397***			2.109***		
	(0.686)			(0.663)		
no. never married sons	2.273***	1.832**	2.648***	2.218***	1.919**	2.482***
	(0.579)	(0.790)	(0.808)	(0.551)	(0.757)	(0.775)
no. never married daughters	0.547	0.014	1.201	0.765	0.020	1.611
	(0.719)	(0.972)	(1.066)	(0.700)	(0.930)	(1.045)
farming	15.576***	15.831***	15.150***	14.542***	14.708***	14.230***
	(0.738)	(1.397)	(1.155)	(0.696)	(1.338)	(1.082)
government	−7.725***	−5.948**	−11.061***	−6.539***	−5.123*	−9.559***
	(1.901)	(2.865)	(2.038)	(1.843)	(2.748)	(1.980)
firm	−8.621***	−9.595***	−7.392***	−7.810***	−8.692***	−6.779***
	(0.999)	(1.719)	(1.543)	(0.949)	(1.646)	(1.440)
individual firm	−8.636***	−9.658***	−7.283***	−8.026***	−9.081***	−6.561***
	(0.840)	(1.076)	(1.525)	(0.770)	(1.030)	(1.368)
self-employed	−5.902***	−7.359***	−4.103***	−4.949***	−6.384***	−3.223**
	(0.942)	(1.283)	(1.461)	(0.913)	(1.228)	(1.425)
household income	−2.115	−16.993	12.086	−9.972	−22.088*	0.466
	(12.344)	(13.029)	(17.413)	(9.881)	(12.468)	(13.536)
education	−0.693***	−0.237	−1.112***	−0.682***	−0.246	−1.083***
	(0.198)	(0.299)	(0.264)	(0.190)	(0.289)	(0.252)
age	2.162***	5.267***	−0.215	2.386***	5.302***	0.155
	(0.792)	(1.154)	(1.077)	(0.767)	(1.112)	(1.053)
financial asset	2.065	1.132	6.512	−5.176	−7.707	2.600
	(9.961)	(11.334)	(16.543)	(7.267)	(10.865)	(15.747)
financial liability	3.669	21.666	−0.757	3.766	21.023	−0.468
	(6.298)	(16.783)	(3.903)	(6.024)	(16.079)	(3.512)
east	−0.113	0.346	−0.570	−0.209	0.623	−1.007
	(0.959)	(1.358)	(1.356)	(0.927)	(1.308)	(1.298)
west	5.054***	4.073***	5.808***	5.234***	4.463***	5.785***
	(0.900)	(1.257)	(1.242)	(0.874)	(1.211)	(1.208)
northeast	−2.588*	−1.291	−3.895**	−2.367*	−1.127	−3.655**
	(1.361)	(2.185)	(1.874)	(1.318)	(2.106)	(1.815)
wave dummy	3.753**	2.151	4.153*	2.849*	1.030	3.462
	(1.768)	(2.640)	(2.292)	(1.699)	(2.535)	(2.168)
Observations	5802	2686	3116	5802	2686	3116
χ^2	2363.454	534.747	1193.809	2374.549	521.323	1221.952

Table 4.9: The effect of NRSPI program on labor supply of agricultural work. We fit model (4.2) to the rural observations with age below 60 in these regressions. In columns (1) to (3), the dependent variable is the agricultural working hours per week; in columns (4) to (6), it is the own-field agricultural working hours per week. Columns (1) and (4) use all rural observations below age 60, columns (2) and (5) use only the male rural observations below age 60, and columns (3) and (6) use only the female rural observations below age 60. The constant terms and coefficients on the number of sons and daughters, and whether individuals need to take care of grandchildren or parents are omitted from the report.

	(1)	(2)	(3)	(4)	(5)	(6)
	retirement status			non-agr. work status		
	All	Male	Female	All	Male	Female
pension	0.281**	−0.059	0.237*	−0.130	−0.148	0.024
	(0.120)	(0.154)	(0.125)	(0.079)	(0.138)	(0.077)
benefits	−0.297**	0.112	−0.256***	0.125*	0.059	0.040
	(0.117)	(0.186)	(0.090)	(0.068)	(0.138)	(0.051)
self-reported health	−0.194***	−0.231***	−0.159***	0.045***	0.072***	0.028***
	(0.014)	(0.021)	(0.017)	(0.007)	(0.013)	(0.009)
urban	0.233***	0.182***	0.257***	−0.046***	−0.052**	−0.032*
	(0.022)	(0.028)	(0.025)	(0.014)	(0.020)	(0.016)
male	−0.093***			0.050***		
	(0.010)			(0.006)		
no. never married sons	−0.025***	−0.012	−0.033**	−0.002	−0.008	0.007
	(0.009)	(0.013)	(0.013)	(0.006)	(0.010)	(0.008)
married	−0.101***	−0.125***	−0.090***	−0.000	0.038**	−0.013
	(0.016)	(0.025)	(0.019)	(0.009)	(0.016)	(0.010)
agri-hukou	−0.023	−0.020	−0.051	0.052**	0.040	0.081***
	(0.031)	(0.043)	(0.041)	(0.022)	(0.031)	(0.029)
no. never married daughters	0.012	0.002	0.019	0.001	−0.000	0.009
	(0.012)	(0.015)	(0.017)	(0.008)	(0.012)	(0.011)
farming	−0.018	−0.002	−0.046**	−0.019	−0.016	−0.038*
	(0.016)	(0.019)	(0.023)	(0.014)	(0.018)	(0.021)
government	0.169***	0.129***	0.207***	0.489***	0.589***	0.352***
	(0.038)	(0.038)	(0.051)	(0.049)	(0.060)	(0.075)
firm	0.169***	0.168***	0.155***	0.517***	0.554***	0.457***
	(0.024)	(0.027)	(0.036)	(0.030)	(0.035)	(0.050)
individual firm	0.079***	0.065***	0.099***	0.691***	0.738***	0.601***
	(0.013)	(0.014)	(0.023)	(0.015)	(0.018)	(0.026)
self-employed	−0.073***	−0.022	−0.145***	0.844***	0.819***	0.871***
	(0.013)	(0.015)	(0.023)	(0.011)	(0.015)	(0.015)
household income	−0.087	0.185	−0.238	0.429***	0.472***	0.221*
	(0.129)	(0.170)	(0.203)	(0.096)	(0.150)	(0.125)
education	0.010***	0.005	0.011**	−0.004**	−0.006**	−0.001
	(0.003)	(0.004)	(0.004)	(0.002)	(0.003)	(0.002)
age	0.116***	0.090***	0.133***	−0.037***	−0.028*	−0.039***
	(0.017)	(0.024)	(0.021)	(0.010)	(0.017)	(0.012)
financial asset	0.115	0.021	0.790**	0.010	0.004	−0.079
	(0.115)	(0.085)	(0.327)	(0.079)	(0.085)	(0.195)
financial liability	0.151	−0.127	0.207	−0.122	−0.084	−0.155
	(0.093)	(0.162)	(0.154)	(0.093)	(0.169)	(0.114)
Observations	12356	5876	6480	12356	5876	6480
χ^2	1542.615	603.720	999.662	20715.841	11839.810	9355.492

Table 4.10: The effect of NRSPI program on the retirement status and work status of non-agricultural work. We fit model (4.1) to all the observations in both the rural and urban side with age above 45. In columns (1), (2), and (3), the dependent variable is the retirement status; in columns (4), (5), and (6), it is the non-agricultural work status. Columns (1) and (4) use all observations, columns (2) and (5) use only the male observations, and columns (3) and (6) use only the female observations. The constant terms and coefficients on the districts and wave dummies, the number of sons and daughters, and whether individuals need to take care of grandchildren or parents are omitted from the report.

	(1)	(2)	(3)	(4)	(5)	(6)
	agriculture work status			agr. work for own household		
	All	Male	Female	All	Male	Female
pension	−0.126	0.133	−0.101	−0.453***	−0.403**	−0.413**
	(0.101)	(0.140)	(0.132)	(0.145)	(0.167)	(0.197)
benefits	0.201**	−0.163	0.169*	0.208	0.196	0.133
	(0.100)	(0.176)	(0.101)	(0.135)	(0.127)	(0.191)
self-reported health	0.184***	0.212***	0.153***	0.029**	0.041**	0.021
	(0.014)	(0.021)	(0.018)	(0.011)	(0.017)	(0.015)
urban	−0.211***	−0.169***	−0.234***	−0.027	0.019	−0.065*
	(0.020)	(0.026)	(0.026)	(0.024)	(0.027)	(0.037)
male	0.076***			0.003		
	(0.009)			(0.008)		
no. never married sons	0.032***	0.014	0.042***	−0.004	0.012	−0.021*
	(0.009)	(0.012)	(0.012)	(0.008)	(0.011)	(0.012)
married	0.099***	0.107***	0.098***	−0.025*	−0.010	−0.035*
	(0.015)	(0.024)	(0.020)	(0.014)	(0.022)	(0.018)
agri-hukou	−0.026	−0.015	−0.017	0.008	0.009	0.018
	(0.029)	(0.040)	(0.042)	(0.031)	(0.038)	(0.051)
no. never married daughters	−0.005	0.002	−0.013	−0.014	−0.015	−0.011
	(0.011)	(0.014)	(0.016)	(0.011)	(0.015)	(0.015)
farming	0.793***	0.861***	0.718***	0.561***	0.449	0.782***
	(0.013)	(0.015)	(0.021)	(0.211)	(0.317)	(0.035)
government	−0.073***	−0.059*	−0.087*	0.044**	0.044*	0.056**
	(0.028)	(0.033)	(0.048)	(0.022)	(0.026)	(0.026)
firm	−0.124***	−0.132***	−0.094***	0.010	0.017	−0.002
	(0.021)	(0.026)	(0.036)	(0.023)	(0.026)	(0.045)
individual firm	−0.067***	−0.042***	−0.105***	−0.022	−0.019	−0.033
	(0.011)	(0.013)	(0.021)	(0.014)	(0.016)	(0.029)
self-employed	0.006	−0.004	0.016	−0.019	−0.011	−0.033
	(0.010)	(0.013)	(0.017)	(0.015)	(0.018)	(0.026)
household income	−0.171	−0.483***	0.064	0.072	0.039	0.128
	(0.122)	(0.163)	(0.182)	(0.144)	(0.176)	(0.233)
education	−0.010***	−0.006*	−0.011***	0.001	0.001	0.002
	(0.003)	(0.004)	(0.004)	(0.002)	(0.003)	(0.003)
age	−0.118***	−0.089***	−0.132***	0.059***	0.059**	0.056*
	(0.016)	(0.023)	(0.021)	(0.020)	(0.026)	(0.030)
financial asset	−0.136	−0.018	−0.722**	−0.363	−0.478	0.015
	(0.085)	(0.065)	(0.287)	(0.269)	(0.336)	(0.378)
financial liability	−0.108	0.101	−0.170**	−0.221	−0.045	−0.513
	(0.096)	(0.155)	(0.083)	(0.199)	(0.210)	(0.380)
Observations	12356	5876	6480	7688	3858	3830
χ^2	8867.383	6456.472	3777.320	115.216	64.448	43451.780

Table 4.11: The effect of NRSPI program on the work status of agricultural work. We fit model (4.1) to all the observations in both the rural and urban side with age above 45. In columns (1), (2), and (3), the dependent variable is the agricultural work status; in columns (4), (5), and (6), it is the agricultural work status on their own household field. Columns (1) and (4) use all observations, columns (2) and (5) use only the male observations, and columns (3) and (6) use only the female observations. The constant terms and coefficients on the districts and wave dummies, the number of sons and daughters, and whether individuals need to take care of grandchildren or parents are omitted from the report.

	(1)	(2)	(3)	(4)	(5)	(6)
	weekly working hours			hours non-agri. work		
	All	Male	Female	All	Male	Female
pension	−27.120***	−7.188	−20.446**	−5.128	4.665	−3.249
	(8.880)	(15.534)	(9.873)	(4.985)	(9.235)	(5.422)
benefits	19.408**	−7.572	17.526**	6.143	−6.007	6.904*
	(8.082)	(16.857)	(7.797)	(4.388)	(10.735)	(3.832)
self-reported health	8.056***	10.722***	5.663***	2.594***	3.454***	1.930***
	(0.798)	(1.272)	(1.016)	(0.492)	(0.871)	(0.569)
urban	−10.227***	−9.078***	−9.923***	−1.988*	−1.501	−1.725
	(1.373)	(2.071)	(1.655)	(1.019)	(1.286)	(1.225)
male	6.768***			2.869***		
	(0.655)			(0.412)		
no. never married sons	1.892***	2.066**	1.697*	0.168	0.203	0.380
	(0.676)	(1.024)	(0.926)	(0.421)	(0.697)	(0.531)
married	5.352***	11.178***	2.167*	0.730	3.505***	−0.433
	(0.950)	(1.795)	(1.124)	(0.565)	(1.188)	(0.637)
agri-hukou	3.985**	6.179**	3.243	2.233	4.471**	1.049
	(1.902)	(2.817)	(2.387)	(1.617)	(1.833)	(2.088)
no. never married daughters	−0.525	−0.978	0.197	−0.267	−0.877	0.562
	(0.872)	(1.186)	(1.282)	(0.561)	(0.850)	(0.732)
farming	7.767***	9.396***	5.305***	−4.889***	−4.742***	−5.823***
	(1.295)	(1.767)	(1.917)	(1.113)	(1.001)	(1.620)
government	12.178***	16.774***	6.679	19.888***	24.291***	13.868***
	(3.423)	(4.053)	(5.070)	(3.057)	(1.899)	(4.654)
firm	17.717***	21.141***	13.073***	27.607***	32.004***	20.531***
	(2.193)	(2.682)	(3.351)	(1.887)	(1.250)	(3.042)
individual firm	27.224***	30.885***	21.347***	36.689***	41.246***	28.974***
	(1.302)	(1.642)	(2.259)	(1.099)	(0.861)	(1.809)
self-employed	34.941***	33.288***	36.786***	41.579***	41.170***	41.686***
	(1.436)	(1.910)	(2.140)	(1.155)	(0.959)	(1.774)
household income	45.537***	39.412**	36.719**	51.758***	61.578***	30.228***
	(11.813)	(19.132)	(14.769)	(7.916)	(10.162)	(8.553)
education	−0.840***	−0.468	−1.046***	0.046	0.082	0.126
	(0.202)	(0.308)	(0.262)	(0.130)	(0.198)	(0.160)
age	−2.772**	−0.337	−5.024***	−2.004***	−1.900*	−2.163***
	(1.079)	(1.697)	(1.290)	(0.682)	(1.154)	(0.795)
financial asset	−2.441	1.104	−34.747	3.942	4.558	−13.740
	(7.322)	(6.815)	(29.714)	(4.586)	(4.576)	(20.403)
financial liability	−0.044	34.192*	−7.505	0.529	22.898	−5.479
	(6.750)	(20.718)	(5.866)	(5.716)	(14.051)	(5.522)
Observations	11444	5400	6044	11444	5400	6044
χ^2	2903.749	1551.045	1130.035	4911.589	6543.491	1498.620

Table 4.12: The effect of NRSPI program on labor supply. We fit model (4.1) to all the observations in both the rural and urban side with age above 45. In columns (1), (2), and (3), the dependent variable is the total working hours per week; in columns (4), (5), and (6), it is the weekly non-agricultural working hours. Columns (1) and (4) use all observations, columns (2) and (5) use only the male observations, and columns (3) and (6) use only the female observations. The constant terms and coefficients on the districts and wave dummies, the number of sons and daughters, and whether individuals need to take care of grandchildren or parents are omitted from the report.

	(1)	(2)	(3)	(4)	(5)	(6)
		hours agri. work		hours agri. work for own household		
	All	Male	Female	All	Male	Female
pension	−20.479***	−12.598	−17.053**	−20.634***	−14.064	−17.829**
	(6.172)	(10.274)	(7.356)	(6.137)	(9.743)	(7.144)
benefits	12.661**	−2.492	11.141**	14.086**	2.930	11.458**
	(5.736)	(11.180)	(5.493)	(5.927)	(10.946)	(5.477)
self-reported health	5.464***	7.291***	3.733***	5.121***	7.023***	3.336***
	(0.625)	(0.882)	(0.830)	(0.618)	(0.874)	(0.819)
urban	−8.165***	−7.269***	−8.225***	−8.326***	−7.354***	−8.491***
	(0.788)	(1.303)	(0.972)	(0.774)	(1.292)	(0.894)
male	3.851***			3.699***		
	(0.492)			(0.484)		
no. never married sons	1.726***	1.877***	1.402*	1.701***	1.987***	1.272*
	(0.507)	(0.725)	(0.716)	(0.496)	(0.710)	(0.693)
married	4.642***	7.843***	2.681***	4.408***	7.210***	2.634***
	(0.722)	(1.228)	(0.892)	(0.715)	(1.206)	(0.890)
agri-hukou	1.898*	2.174	2.097	1.439	1.516	1.797
	(1.064)	(1.842)	(1.404)	(1.060)	(1.833)	(1.397)
no. never married daughters	−0.244	−0.300	−0.232	−0.005	−0.089	0.101
	(0.652)	(0.904)	(0.971)	(0.647)	(0.875)	(0.963)
farming	12.590***	13.712***	11.615***	11.834***	12.868***	10.962***
	(0.542)	(1.068)	(0.842)	(0.531)	(1.033)	(0.814)
government	−7.442***	−7.591***	−7.009***	−7.045***	−7.160***	−6.496***
	(1.255)	(2.015)	(1.846)	(1.277)	(1.954)	(1.828)
firm	−9.292***	−10.601***	−7.183***	−8.956***	−10.114***	−6.953***
	(0.898)	(1.351)	(1.461)	(0.879)	(1.298)	(1.424)
individual firm	−9.016***	−10.541***	−7.051***	−8.735***	−10.165***	−6.791***
	(0.651)	(0.936)	(1.135)	(0.611)	(0.896)	(1.042)
self-employed	−6.282***	−8.255***	−4.423***	−5.678***	−7.471***	−3.918***
	(0.743)	(1.033)	(1.040)	(0.718)	(0.994)	(1.022)
household income	−4.384	−24.503**	10.897	−7.976	−24.671**	4.800
	(8.752)	(10.993)	(11.594)	(7.617)	(10.560)	(9.660)
education	−0.898***	−0.545***	−1.195***	−0.855***	−0.506**	−1.132***
	(0.149)	(0.200)	(0.200)	(0.147)	(0.198)	(0.195)
age	−0.942	1.832	−2.955***	−0.868	1.544	−2.590***
	(0.806)	(1.204)	(1.019)	(0.788)	(1.176)	(0.992)
financial asset	−6.362	−3.232	−24.188	−8.157	−5.072	−32.504*
	(4.389)	(4.736)	(18.329)	(4.968)	(4.649)	(17.853)
financial liability	−0.119	8.695	−2.176	0.118	9.195	−1.957
	(3.893)	(15.210)	(3.141)	(3.795)	(14.607)	(2.969)
Observations	11444	5400	6044	11444	5400	6044
χ^2	2744.097	1086.610	1308.488	2555.734	1026.827	1278.832

Table 4.13: The effect of NRSPI program on labor supply of agricultural work. We fit model (4.1) to all the observations in both the rural and urban side with age above 45. In columns (1), (2), and (3), the dependent variable is the agricultural working hours per week; in columns (4), (5), and (6), it is the weekly agricultural working hours on their own household field. Columns (1) and (4) use all observations, columns (2) and (5) use only the male observations, and columns (3) and (6) use only the female observations. The constant terms and coefficients on the districts and wave dummies, the number of sons and daughters, and whether individuals need to take care of grandchildren or parents are omitted from the report.

	(1)	(2)	(3)	(4)	(5)	(6)
	All		Female		Male	
	LP	Probit	LP	Probit	LP	Probit
pension enrollment(%)	0.112***	0.777**	0.145**	0.795*	0.038	0.575
	(0.041)	(0.321)	(0.057)	(0.415)	(0.055)	(0.455)
self-reported health	−0.216***	−0.320***	−0.173***	−0.258***	−0.233***	−0.368***
	(0.015)	(0.049)	(0.020)	(0.060)	(0.022)	(0.069)
married	−0.131***	−0.816***	−0.112***	−0.625***	−0.130***	−0.855***
	(0.016)	(0.133)	(0.021)	(0.160)	(0.024)	(0.183)
agriculture-hukou(%)	−0.124***	−0.870***	−0.146**	−0.974**	−0.096	−0.683
	(0.045)	(0.323)	(0.057)	(0.450)	(0.066)	(0.425)
no. never married sons	−0.028***	−0.161**	−0.037***	−0.205**	−0.013	−0.042
	(0.008)	(0.073)	(0.011)	(0.097)	(0.011)	(0.104)
no. never married daughters	0.013	0.180*	0.022	0.210*	0.004	0.113
	(0.011)	(0.099)	(0.017)	(0.127)	(0.013)	(0.152)
no. sons	0.013**	0.102***	0.019***	0.141***	0.003	−0.003
	(0.005)	(0.036)	(0.007)	(0.052)	(0.007)	(0.049)
no. daughter	0.002	0.030	0.000	0.033	0.002	0.004
	(0.004)	(0.031)	(0.006)	(0.041)	(0.006)	(0.044)
farming(%)	−0.062***	−0.762***	−0.091***	−0.791***	−0.030	−0.592***
	(0.018)	(0.156)	(0.031)	(0.222)	(0.021)	(0.192)
government(%)	0.116***	0.686***	0.193**	1.078***	0.089**	0.562*
	(0.039)	(0.248)	(0.078)	(0.406)	(0.041)	(0.306)
firm(%)	0.135***	0.865***	0.113**	0.654**	0.164***	1.175***
	(0.025)	(0.181)	(0.044)	(0.285)	(0.030)	(0.234)
other employed(%)	0.060***	0.253**	0.088***	0.517***	0.060***	0.294*
	(0.013)	(0.115)	(0.025)	(0.186)	(0.014)	(0.152)
self-employed(%)	−0.055***	−1.332***	−0.103***	−1.383***	−0.011	−0.981***
	(0.013)	(0.210)	(0.022)	(0.292)	(0.015)	(0.250)
household income(CNY/year)	−0.039	−2.648**	−0.178	−2.670	0.120	−1.772
	(0.138)	(1.287)	(0.224)	(1.768)	(0.166)	(1.793)
education	−0.001	−0.083***	0.009**	0.030	0.005	−0.017
	(0.003)	(0.024)	(0.004)	(0.032)	(0.004)	(0.033)
age(year)	0.098***	0.819***	0.123***	0.874***	0.095***	0.973***
	(0.007)	(0.099)	(0.010)	(0.140)	(0.009)	(0.144)
financial asset(CNY)	0.415**	1.165	0.416	−0.395	0.412*	2.247*
	(0.191)	(1.252)	(0.293)	(2.871)	(0.242)	(1.343)
financial liability(CNY)	0.047	0.574	0.124	1.169	−0.156	−4.881
	(0.136)	(1.016)	(0.110)	(1.353)	(0.170)	(4.288)
care child(%)	−0.019**	−0.013	−0.004	0.094	−0.033***	−0.122
	(0.009)	(0.072)	(0.013)	(0.096)	(0.012)	(0.109)
careparent(%)	0.000	−0.179	−0.004	−0.265	−0.006	−0.139
	(0.013)	(0.143)	(0.019)	(0.180)	(0.017)	(0.232)
Observations	11300	11300	5884	5884	5416	5416
χ^2	1238.746		786.355		529.198	

Table 4.14: The estimation results of the Probit model. In all columns, the dependent variable is the retirement status; Columns (1), (3), and (5) report the linear probability model estimation results and columns (2), (4), and (6) report the Probit model estimation results. Rural individuals younger than 60 are used in the estimation in columns (1) and (2). Columns (3) and (4) only use the female subsample and columns (5) and (6) only use the male subsample. The constant terms and coefficients on the districts and wave dummies are omitted from the report.

bandwidth	(1) retirement status Female	(2) Male	(3) weekly working hours Female	(4) Male
3 years	−0.327	0.137	15.734	3.056
	(0.358)	(0.488)	(20.590)	(20.257)
5 years	0.027	−0.106	−18.067**	8.006
	(0.151)	(0.171)	(8.914)	(11.477)
8 years	0.089	0.024	−0.113	−1.434
	(0.090)	(0.111)	(5.742)	(8.521)
10 years	0.149*	−0.046	−1.976	2.346
	(0.076)	(0.087)	(4.788)	(7.039)
15 years	0.036	0.033	2.261	0.770
	(0.060)	(0.062)	(3.815)	(5.238)
20 years	−0.015	−0.004	4.201	1.934
	(0.055)	(0.055)	(3.385)	(4.398)

Table 4.15: The effect of receiving pension benefits on the retirement status and weekly working hours for females and males using regression discontinuity design. The bandwidth of the sample varies from 3 years to 20 years with the cut-off age equal to 60 years old. In columns (1) and (2), the dependent variable is the retirement status; in columns (3) and (4), it is the weekly working hours. The other coefficients are omitted from this report.

	pension enrollment		pension income		self-reported health	
	RE panel	Pooled OLS	RE panel	Pooled OLS	RE panel	Pooled OLS
	(1)	(2)	(3)	(4)	(5)	(6)
duration	0.085***	0.087***	2.630***	3.058***	0.010	0.012*
	(0.004)	(0.003)	(0.351)	(0.347)	(0.007)	(0.007)
federal revenue	−0.028***	−0.026***	2.425***	2.380***	−0.010	−0.012
	(0.005)	(0.005)	(0.502)	(0.455)	(0.010)	(0.009)
physical	−0.003**	−0.003**	−0.239*	−0.291**	−0.079***	−0.085***
	(0.001)	(0.001)	(0.122)	(0.119)	(0.002)	(0.002)
pain	−0.008	−0.007	0.695	0.921	−0.247***	−0.277***
	(0.011)	(0.011)	(1.055)	(1.067)	(0.021)	(0.021)
dyslipidemia	−0.067**	−0.069**	7.301**	8.608**	−0.081	−0.071
	(0.034)	(0.034)	(3.323)	(3.438)	(0.066)	(0.068)
diabetes	0.096**	0.097**	1.854	1.833	−0.330***	−0.366***
	(0.042)	(0.042)	(4.081)	(4.206)	(0.081)	(0.083)
cancer	−0.093	−0.098	5.746	6.181	−0.718***	−0.816***
	(0.096)	(0.096)	(9.373)	(9.574)	(0.186)	(0.190)
heart	0.083**	0.080**	2.613	2.295	−0.259***	−0.285***
	(0.032)	(0.032)	(3.166)	(3.243)	(0.063)	(0.064)
stroke	0.102	0.100	8.666	9.137	−0.274**	−0.298**
	(0.065)	(0.065)	(6.358)	(6.465)	(0.126)	(0.128)
agriculture-hukou(%)	0.148***	0.148***	4.521	4.583	−0.038	−0.034
	(0.038)	(0.037)	(4.107)	(3.656)	(0.082)	(0.073)
male(%)	−0.010	−0.010	−1.313	−1.407	0.001	−0.007
	(0.009)	(0.009)	(0.980)	(0.876)	(0.020)	(0.017)
no. never married sons	−0.012	−0.013	−3.638***	−2.920***	−0.039**	−0.045***
	(0.009)	(0.009)	(0.901)	(0.889)	(0.018)	(0.018)
no. never married daughters	−0.005	−0.003	−3.926***	−3.528***	−0.035	−0.048**
	(0.012)	(0.012)	(1.220)	(1.211)	(0.024)	(0.024)
farming(%)	0.105***	0.107***	0.360	0.132	−0.026	−0.035
	(0.017)	(0.016)	(1.666)	(1.628)	(0.033)	(0.032)
government(%)	0.006	0.006	1.013	1.472	0.002	−0.020
	(0.034)	(0.033)	(3.480)	(3.343)	(0.069)	(0.066)
firm(%)	0.008	0.006	0.206	0.081	0.054	0.038
	(0.023)	(0.023)	(2.305)	(2.281)	(0.046)	(0.045)
other employed(%)	−0.001	−0.001	1.431	1.214	0.080***	0.080***
	(0.014)	(0.014)	(1.430)	(1.411)	(0.028)	(0.028)
self-employed(%)	−0.019	−0.018	1.915	2.183	0.152***	0.161***
	(0.016)	(0.016)	(1.610)	(1.597)	(0.032)	(0.032)
household income(CNY/year)	0.153	0.169	−24.688	−23.799	0.768**	0.892***
	(0.158)	(0.158)	(15.561)	(15.778)	(0.308)	(0.313)
education	−0.000	−0.000	0.137	0.115	0.010	0.008
	(0.003)	(0.003)	(0.298)	(0.266)	(0.006)	(0.005)
age(year)	−0.001	−0.001	13.182***	13.431***	0.023*	0.029**
	(0.006)	(0.006)	(0.650)	(0.594)	(0.013)	(0.012)
financial asset(CNY)	−0.438**	−0.455***	24.886	25.362	1.689***	1.829***
	(0.172)	(0.171)	(17.173)	(17.072)	(0.340)	(0.339)
financial liability(CNY)	0.127	0.128	−7.384	0.065	−0.098	−0.168
	(0.156)	(0.156)	(15.196)	(15.562)	(0.301)	(0.309)
Observations	11300	11300	11300	11300	11300	11300
Wald chi2	5301.181		1770.042		2069.700	
Prob > chi2	0.000	0.000	0.000	0.000	0.000	0.000

Table 4.16: The results of the weak instrument test. In columns (1) and (2), (3) and (4), (5) and (6), the dependent variable is the pension enrollment status, the pension benefits, and the self-reported health, respectively. The rural samples are used in the estimation. Columns (1), (3), and (5) show the RE estimation results and columns (2), (4), and (6) show the pooled OLS estimation results. The constant terms and coefficients on the districts and wave dummies, the number of sons and daughters, and whether individuals need to take care of grandchildren or parents are omitted from the report.